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EFFECT OF CORN, WHEAT, AND BARLEY IN THE DIET ON THE PHYSICAL AND CHEMICAL COMPOSITION OF FRYERS AND ROASTERS [1]

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INTRODUCTION

While much has been learned from studies of the effects of grains on growth and egg production in poultry, somewhat less is known of the effects of grains upon the physical and chemical composition of the meat produced. In 1936, the writers began a series of experiments which involved a comprehensive study of the effects of simple rations composed principally of corn, wheat, or barley upon the physical and chemical composition of fryers and roasters. The tests were made with five general objectives in mind, namely, to determine: (1) The rate of gain in body weight of birds on different feeds and the amount of feed required to produce a unit of gain; (2) the association of body weight and observed grade with certain external measurements of the dressed carcass; (3) the relationship of these body measurements to the total amount of edible meat; (4) the effect of the different cereals upon the quantity of light meat, dark meat, skin and subcutaneous fat, and abdominal fat; and (5) the effects of the cereals upon the deposition of fat in these different classes of edible meat as an indication of edible quality.

REVIEW OF LITERATURE

Cruickshank (*3*) [2] reported that the fat from birds fed barley was firmer than that from birds fed corn; however, the fat of the corn-fed birds was not objectionally soft. It was also noted by Gutteridge (*4*) that the feeding of White Leghorn capons in pens was relatively inefficient as compared to the feeding in fattening crates.

With reference to the effect of environment on fattening poultry, MacDonald and McMurray (*13*) stated that during the summer months trough-fed range birds made as good gains as trough-fed birds kept in a fattening shed. With roasters, it was found by Harshaw (*5*) that the percentage of protein and ash was significantly higher in the leg muscle of range birds, and that the protein content of the breast muscle was also higher. The percentage of fat in the edible portions was generally higher in the range-reared than in the confined birds, but the differences were not statistically significant.

Harshaw (*6*) reported that the absolute gain in live weight during fattening increased with age, but the relative gain decreased. The ratio of the leg muscle to dressed weight increased with age, but the

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[2] Italic numbers in parentheses refer to Literature Cited, p. 177.

ratio of the breast muscle to dressed weight remained practically the same. The ratio of the remaining edible portion to dressed weight depended largely on the extent of fattening. In younger birds the moisture increased more than the fat during fattening, but in older birds the reverse was true. The percentage of breast muscle and leg muscle decreased with fattening, while the percentage of the remaining edible portion increased. The fat increased in all edible portions during fattening, but the greatest quantity of new fat was laid down in the "remaining" edible portion (comprising all the edible portions except the breast and leg muscle). Fattening resulted in a decrease in the percentage of protein, ash, and water in the remaining edible portion and the leg muscle, but not in the breast muscle.

Harshaw (*5*) found that the percentages of breast muscle, leg muscle, and the total edible portion were significantly higher for range-reared birds than for confined birds. The percentage of fat was higher in all the edible portions of the fattened birds as compared with that in the unfattened birds. The fattened birds had an average of 85 percent more fat in the breast muscle, 43 percent in the leg muscle, and 57 percent in the remaining edible portion as compared with the unfattened birds. There was usually a lower percentage of protein, ash, and water in the edible portions of the fattened birds, although there was actually an increase in the total amounts of protein, ash, and water. The leg muscle contained a larger proportion of water than the other edible portions.

In a study by Maw et al. (*18*) of Barred Plymouth Rock roasters, it was found that the fat in the edible meat of corn-, wheat-, oat-, and barley-fed birds amounted to 8.95, 6.99, 4.81, and 3.43 percent, respectively. It was further found by Maw and Maw (*21*) that corn meal caused a high percentage of the total body fat to be deposited in the flesh and much less to be deposited in the abdominal cavity and the skin of the bird; whereas the cereals barley, oats, and wheat showed the reverse in varying degrees. On the other hand, Gutteridge (*4*) reported a significant correlation between the percentage of fat in the skin and subcutaneous tissue and that in the abdomen, indicating that fat was distributed in a definite and similar ratio in the depot areas, regardless of the feed given. Crampton (*2*) has presented a good review of the comparative feeding values of the cereals.

More recently, Maw (*17*) noted that single cereal grains gave as good results as combinations of cereals. Corn was superior to wheat, oats, and barley in producing edible meat and fat as well as skin and abdominal fatty tissue. In this work (*17*) the character of body fat was also studied as to iodine number and color.

Maw et al. (*22*) reported that mature roasters fed corn had the largest amount of total fat, those fed wheat the next largest, and those fed barley and oats had least. The length of the fattening period affected the interpretation of the values of these cereals. Corn tended to produce more fat in the flesh and less fat in the skin and abdominal regions, whereas wheat produced more skin and abdominal fats and less flesh fats. In another report, Maw and Maw (*21*) stated that the rations fed had no significant effect upon the distribution of fat in the edible portion of Leghorn broilers.

Physical and chemical studies were made by Harshaw (*7*) on five lots of 12-week-old cockerels. One lot was fed a commonly used

control all-mash ration and the other four were fed rations composed each of corn, wheat, oats, or barley as the only cereal grain with protein, vitamin, and mineral supplements. As compared with the control, the oat- and barley-fed lots had about the same proportion of leg and breast muscle; the wheat- and corn-fed lots had considerably less. The percentage of the remaining edible portion was approximately the same for all five lots. Considering the percentage of total edible portion, the order of the five lots was as follows: Control birds, oat-, barley-, wheat,- and corn-fed. The corn-fed birds were the highest in fat content of edible portions, followed in order by those fed the wheat, control, barley, and oat diets. No difference in the distribution of fat between the edible portions was noted in the birds on the different diets.

A method has been reported by Lloyd (*12*) for estimating the amount of breast fleshing according to which classifications are made of the so-called U, V, and I breasts. The method would serve as a guide in selecting breeding stock for egg production.

Body measurements have been taken by several investigators. Jaap and Penquite (*10*) noted that differences in body conformation of live and dressed birds may be accurately expressed by comparing body weight, shank length, keel length, and minimum anterior body depth. They found that a satisfactory point for measuring breast width is about 1½ inches from the anterior end of the keel on a line toward the insertion of the femurs. Jaap (*9*) also reported breed differences in body conformation as compared with shank length. For example, Cornish aud Game breeds attain a broad, plump breast at an early age, whereas American and English class breeds reach their best market shape at maturity. Brahmas and Giants belong to a group that is thin and angular during growth and only at maturity attains superior body shape. Lerner (*11*) concluded that shank length measured on live birds forms a valid criterion in studies on inherited size differences in fowls. Lloyd (*12*) reported no correlation between meat type and egg production. Market type, however, was judged without the aid of definite body measurements. Maw (*15*) and Maw and Maw (*14*, *20*) have reported on body measurements; they (*14*) found that correlations existed between fattening gains and certain body measurements, which included body length, leg length, and circumference of tibial muscles.

EXPERIMENTAL METHODS

PROCEDURE IN 1936

The first experiment was started in the spring of 1936 with White Plymouth Rock cockerels, which were studied as roasters. During the first 8 weeks the chicks were kept in electrically heated starting batteries. The all-mash starting rations used included 46 pounds of a basal mixture made up of 10 percent of meat and bone scraps used for the first 4 weeks; 15 percent of meat scraps from the fourth to the eighth week; 10 percent of dried buttermilk the first 4 weeks and 5 percent of dried milk from the fourth to the eighth week; pulverized oats 20 percent, alfalfa leaf meal 5 percent, and cod-liver oil 1 percent. To this mixture was added 54 pounds of either ground yellow corn, wheat, or barley. Ninety day-old chicks of both sexes were started on each of these rations, but only the male survivors

were continued on the growing rations. Each of the three groups received the same principal grain that it had received during the starting period. These rations were given throughout the entire growing period (8 to 31 weeks). No finishing rations were tested in 1936. The cockerels were kept in colony brooder houses with access to millet and rape range.

On November 10, at 31 weeks of age, the 10 cockerels whose weights were nearest the mean weight for each group were selected and dressed (semiscald method) after having been starved for 24 hours. They were then chilled at 36° F., weighed, graded, and the body measurements taken. Then they were dissected and the different classes of edible meat separated for chemical analysis. Only one-half of the carcass was used for this analysis.

PROCEDURE IN 1937

Barred Plymouth Rocks were used in the second experiment, which was started on May 5, 1937. About 70 cockerels 8½ weeks of age and of practically equal average weight were placed in each of three colony brooder houses. They were given growing rations similar to those used in 1936 and had access to millet and rape green range.

Finishing rations for fryers and roasters were studied both in batteries and on the range. With fryers, the 3-week finishing period began when the birds were 14 weeks of age and ended at 17 weeks; with roasters, the finishing period began at 24½ weeks and ended at 26½ weeks. With both fryers and roasters, only those 17 birds from each lot whose weights were nearest the average for the lot were selected for battery and range studies of finishing rations. The standard error for body weight was thus reduced. Although the number of individuals studied was also reduced it is believed that these birds were representative of the lots from which they were taken.

At the end of the 2- or 3-week finishing period, 10 birds whose average weights were nearest the average for the lot were selected from each 17-bird group finished on the range and in the battery. These birds were dressed, graded, body measurements were taken, and each carcass was cut in half. One half was used for chemical analyses and the other half for flavor studies (*23*). The methods of analysis were the same as those employed in the 1936 experiments.

DETERMINING DRESSED GRADES

Grades were determined by placing all the carcasses from all the different lots together and aligning them according to the order of breast fleshing. On the basis of breast fleshing, it was then estimated that the best 25 percent of all the dressed carcasses would grade U. S. Special, the next 25 percent U. S. Prime, the third 25 percent U. S. Choice, and the last 25 percent U. S. Commercial. In order to determine the average grade of each group, numerical values of 1, 2, 3, and 4 were given to each U. S. grade. The band numbers of all birds in the different grade classifications were then determined and grouped according to the rations used and the average numerical grade values calculated. By this method, the grader did not know what rations the birds had received until after the grades for all the birds had been determined.

BODY MEASUREMENTS AND GRADES

The present methods of determining the U. S. grade of live or dressed poultry are based upon the observations and opinions of the official grader, and often there is much difference of opinion among graders as to how a bird should be classified. This fact has decided economic importance since lower grades are penalized considerably on the market.

Since the amount of flesh and subcutaneous fat on the carcass has an important influence upon the observed grade, several body measurements were taken with a view to selecting those measurements that are most closely associated with the actual amounts of edible flesh and fat present.

Figure 1, *A*, shows the breast width measurement which was taken five-eighths inch back from the anterior tip of the sternum. A second

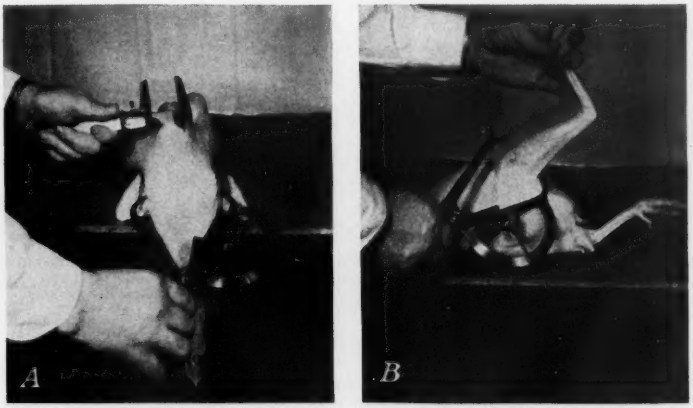

FIGURE 1.—*A*, Breast-width measurement taken five-eighths of an inch from the anterior tip of the sternum with a vernier caliper and shoulder width taken at the widest point with an indicating caliper; *B*, anterior-posterior tibia measurement.

measurement was taken 3 inches back from the anterior tip of the sternum. Both of these measurements, taken with a vernier caliper, give an indication of the breast angle and the amount of flesh at the edge of the sternum. Figure 1, *A*, also shows the location of the shoulder width measurement taken at the widest point. A third measurement (fig. 2, *A*) was taken with an indicating caliper 3 inches back from the anterior tip of the sternum and 1½ inches from the edge at the anterior end of the lateral feather tract. The breast length was simply a measurement of the length of the sternum from anterior to posterior tips. Figure 2, *B*, shows the method of determining the hip width at the widest part of the ilium. The femur and tibia measurements were taken to represent the length of these two bones at the joints when the tibia and femur were held at right angles. Figure 1, *B*, shows the method of taking anterior-posterior tibia measurements at the widest point by holding the metatarsus at a right angle to the tibia. By holding the instrument at right angles to the position of this anterior-posterior measurement, the distance across

the tibia flesh was determined at the thickest point. No femur or tibia measurements were taken for either the roasters reared in 1936 or the fryers in 1937.

INDEX VALUE

Width of breast ⅝ of an inch and 3 inches from the anterior tip of the sternum were the two measurements of greatest value in determining the amount of flesh present. By considering also the length

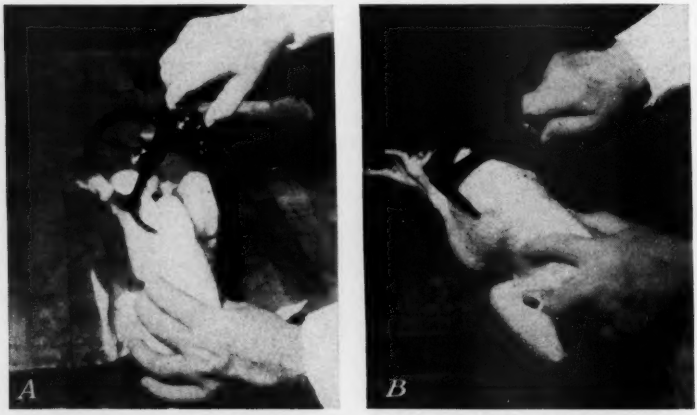

FIGURE 2.—*A*, Breast width measurement taken with an indicating caliper 3 inches from the anterior tip of the sternum and 1½ inches from the edge of the anterior end of the lateral feather tract; *B*, measurement of the hip width taken with a vernier caliper.

of breast and combining the three measurements, an index value was found for each bird according to the equation

$$I=l\ (A^2+B^2)$$

where

I=index value.
l=breast length.
A=width of breast ⅝ of an inch from tip.
B=width of breast 3 inches from tip.

These measurements are most suitable for roasters. The index number obtained by the foregoing equation places most value on breast measurements and has the advantage of permitting statistical treatment.

SEPARATION OF EDIBLE MEATS

The neck was removed and each carcass was cut longitudinally through the spinal column and breastbone, so that there was about the same amount of edible meat on each half of the carcass. All the edible meats were quickly removed from one-half of each carcass, then weighed and classified as to (1) light meat, including the breast and wing muscles; (2) dark meat, including the muscles over the femur, tibia, and ilium; (3) skin and subcutaneous fat, including the fat which adhered to the skin as the skin was pulled from the muscles; and (4) abdominal fatty tissue, which included all fat deposited in the abdomi-

nal cavity. This did not include the fat adhering to the digestive tract. Each of the four samples from each carcass was placed in an airtight sample bottle and stored in a refrigerator at about 35° F. for chemical analysis.

CHEMICAL ANALYSIS OF MEAT

At the time of analysis, the samples were ground and thoroughly mixed by running them through a small meat grinder 10 times. Moisture and fat determinations were both made on the same sample. The samples were introduced (about 3 gm.) into weighed 18-gm. 8-percent butterfat test bottles by a specially made heavy metal syringe which forced the meat out in a filament about 2 mm. in diameter. The bottles were rotated rapidly as the samples were introduced, thus depositing the filament of meat around the outer edges of the bottles and exposing a large surface for rapid loss of moisture. The bottles were placed in a vacuum oven at 28° C. for 36 hours at a pressure of not over 2 mm. of mercury. Under these conditions, very little difficulty was experienced with volatilization of fat.

The fat was determined volumetrically on the dried samples in the butterfat test bottles by a technique developed to eliminate the errors due to the volatility of the chicken fat. Allen (*1*) has recently published a volumetric method for the determination of blood fat. Ten cubic centimeters of 10-percent ammonium hydroxide was added to soften the dried filaments of meat, and 10 cc. of 50-percent sulfuric acid was then introduced to digest the proteins. Warm water was added and the bottles were centrifuged until a clear separation of the fat was obtained in the neck of the test bottles. Readings were made at 98° C. and corrected for the specific gravity of the fat at that temperature.

STATISTICAL ANALYSIS OF DATA

The data have been treated statistically by the analysis of variance method as discussed by Snedecor (*24*). In analyzing the variance in tables with disproportionate subclasses, the method of expected subclass numbers has been used. In all calculations it was assumed that the data represented a random sampling of a normal distribution.

Standard errors of all quantities were determined, and significant differences between means of quantities were determined for the probability of 19 to 1, and for highly significant differences for the probability of 99 to 1. In each table, all differences between means have been tested for significance. Differences which are not significant (odds less than 19 to 1) have not been indicated in the tables. The words "slightly" and "somewhat" are frequently used in the text to denote a trend (odds 19 to 1), but in no case have definite conclusions been based upon trends. The word "appreciable" as used in this report is synonymous with "highly significant."

Tests for significant differences in most cases were made by the usual t test (Snedecor, *24*), in which the standard error of the difference was taken to be equal to the square root of the sum of squares of the standard errors of the means. In several border-line cases (perhaps due to unequal frequencies, but more often to rounded-off numbers) significant differences might have been expected where none are shown. This was due to the fact that the more exact statistical treatment sometimes eliminates the border-line individuals.

EXPERIMENTAL RESULTS

The data presented in table 1 show the growth of the birds, the rations fed, and the feed consumed in the experiments conducted in 1936 and 1937. It is apparent from table 1 that the cockerels that received the barley ration did not gain as much in weight as those that received the wheat or corn in 1936, and there were no highly significant differences between the gains in body weight on any of the three grains in 1937. With respect to the amount of feed required to produce a unit of gain in body weight for roasters, corn was only slightly superior to wheat, while considerably more of the barley ration was required. This agrees with the report of Maw and Maw (*21*), who found the gain-feed ratio in favor of corn, followed in order by wheat and barley. For the fryers produced, wheat appeared most efficient, barley less so, and corn least.

TABLE 1.—*Average weights during growing period as related to feed consumption, and relative values of corn, wheat, and barley rations when fed to range-reared White Plymouth Rock roasters in 1936 and to Barred Plymouth Rock fryers and roasters in 1937*

Ration	Birds at beginning of test	Age of birds at beginning of test	Average initial weight	Birds at end of growing period	Age of birds at end of growing period	Average weight at end of growing period	Gain in weight [2]	Feed per unit of gain	Feed consumed per bird	Grain as proportion of total feed intake	Grain in total ration actually consumed during growing period
	No.	*Weeks*	*Grams*	*No.*	*Weeks*	*Grams*	*Grams*	*Grams*	*Lb.*	*Pct.*	*Pct.*
WHITE PLYMOUTH ROCK ROASTERS, 1936 [1]											
Corn	38	8	[3] 449.2	28	31	2,946.3	2,548.9	8.84	49.64	41.5	78.9
Wheat	57	8	[4] 543.6	33	31	[3] 3,055.1	[5] 2,520.4	8.86	49.21	55.1	83.8
Barley	56	8	507.4	44	31	2,799.2	2,296.3	9.11	46.08	48.2	81.4
BARRED PLYMOUTH ROCK FRYERS, 1937 [6]											
Corn	70	8½	549.5	69	14	[7] 1,135.6	[7] 586.1	6.08	7.85	32.5	72.3
Wheat	70	8½	554.3	70	14	1,227.0	672.7	5.07	7.52	32.7	72.4
Barley	72	8½	556.3	68	14	1,164.4	608.1	5.56	7.45	31.5	71.9
BARRED PLYMOUTH ROCK ROASTERS, 1937 [6]											
Corn	44	16½	1,568.6	42	24½	2,252.2	682.4	7.17	10.77	58.4	82.9
Wheat	45	16½	1,636.0	44	24½	2,290.8	648.9	7.39	10.56	73.2	89.0
Barley	46	16½	1,594.9	46	24½	2,239.7	644.8	8.91	12.65	60.1	83.6

[1] 64 percent of grain was added to the following basal mixture: Pulverized oats 20 percent, meat and bone scraps 10, dried buttermilk 5, and salt 1 percent. The same principal whole grain used in the mash was also given to each lot ad libitum as their sole grain.

[2] Gains were calculated by subtracting the initial weights of survivors from their final weights. In the corn group, for example, the average initial weight of the survivors was 430.9 gm. Initial weights given include the average weights of all cockerels started on the experiment.

[3] Highly significant greater response to wheat and barley than to corn.

[4] Significantly greater response to wheat than to barley.

[5] Highly significant greater response to wheat than to barley.

[6] 59 percent of grain was added to the following basal mixture: Pulverized oats 20, meat and bone scraps 10, alfalfa-leaf meal 5, dried buttermilk 5, and salt 1 percent. The same principal whole grain used in the mash was also given to each lot ad libitum as their sole grain.

[7] Significantly greater response to wheat than to corn.

The percentage of grain of the total feed consumed varied considerably with the roasters. This was due to the fact that both the growing ration of mash and the grain were fed ad libitum in hoppers and there was a tendency for the cockerels receiving either wheat or barley to consume more of these grains in proportion to mash than those receiving

corn. Consequently, a somewhat larger percentage of the total ration ingested consisted of wheat, followed in order by barley and corn. There were practically no differences between the fryer groups, as will be noted in the last two columns of table 1.

During the finishing period studied in the 1937 experiments, an all-mash ration was used. Consequently, the percentage of cereal grain in the total ration consumed remained constant at 62 percent.

TABLE 2.—*Average weights of birds during finishing period as related to feed consumption, and relative value of corn, wheat, and barley when fryers and roasters were range- and battery-fed in 1937* [1]

Ration	Birds finishing test	Age	Average initial weight	Birds at end of finishing period	Age of birds at end of finishing period	Average weight at end of finishing period [2]	Gain in weight [3]	Feed per unit of gain	Feed consumed per bird
	Number	*Wks.*	*Grams*	*Number*	*Weeks*	*Grams*	*Grams*	*Grams*	*Pounds*
RANGE-FED FRYERS									
Corn	16	14	1,156.7	15	17	[4] 1,685.5	[4] 519.5	3.87	4.43
Wheat	16	14	[5] 1,219.0	16	17	[6] 1,682.0	[6] 463.0	4.20	4.29
Barley	17	14	1,175.1	17	17	1,547.1	372.0	5.46	4.48
BATTERY-FED FRYERS									
Corn	17	14	1,149.6	17	17	1,571.8	422.1	3.70	3.44
Wheat	16	14	[8] 1,217.3	16	17	1,604.5	387.2	4.31	3.68
Barley	17	14	1,173.6	17	17	1,633.2	[7] 459.6	4.18	4.24
RANGE- AND BATTERY-FED FRYERS COMBINED									
Corn	33	14	1,153.1	32	17	1,625.1	[8] 467.8		
Wheat	32	14	[9] 1,218.2	32	17	1,643.3	425.1		
Barley	34	14	[10] 1,174.3	34	17	1,590.1	415.8		
RANGE-FED ROASTERS									
Corn	17	24½	2,291.1	17	26½	2,532.8	241.6	6.57	3.50
Wheat	17	24½	2,294.0	17	26½	2,515.4	231.1	6.98	3.56
Barley	16	24½	2,223.3	16	26½	2,416.4	193.1	9.36	3.98
BATTERY-FED ROASTERS									
Corn	17	24½	2,284.2	16	26½	[4] 2,660.6	[4] 380.8	5.62	4.72
Wheat	17	24½	2,283.7	17	26½	[11] 2,583.8	[6] 300.1	7.16	4.73
Barley	17	24½	2,246.5	17	26½	[11] 2,443.0	210.2	10.16	4.71
RANGE- AND BATTERY-FED ROASTERS COMBINED									
Corn	34	24½	2,287.7	33	26½	[4] 2,594.8	[4] 309.1		
Wheat	34	24½	2,288.8	33	26½	[11] 2,550.6	[6] 266.6		
Barley	33	24½	2,235.2	33	26½	2,430.1	201.7		

[1] 62 percent of grain was added to the following basal mixture: Pulverized oats 20 percent, dried buttermilk 13, meat and bone scraps 5. Range-fed birds received the dry mash; battery-fed birds received the mash with water mixed in to make a paste of the proper consistency, the corn mixture requiring 55, the wheat 58, and the barley 62 percent of moisture for the fryers, and 60, 62, and 65 percent for the roasters.

[2] The response of corn-fed fryers was significantly greater on the range than in the battery.

[3] The response of both corn-fed and wheat-fed fryers was highly significantly greater on the range than in the battery; the response of both barley-fed fryers and corn-fed roasters was highly significantly greater in the battery than on the range; the response of wheat-fed roasters was significantly greater in the battery than on the range.

[4] Highly significantly greater response to corn than to barley.

[5] Significantly greater response to wheat than to corn.

[6] Highly significantly greater response to wheat than to barley.

[7] Highly significantly greater response to barley than to wheat.

[8] Significantly greater response to corn than to barley.

[9] Highly significantly greater response to wheat than to corn.

[10] Significantly greater response to wheat than to barley.

[11] Significantly greater response to wheat than to barley.

Table 2 gives the average body weights and gains during the finishing period for the fryers and roasters produced in 1937. No finishing

tests were conducted in 1936. Contrary to the results of 1936, no appreciable differences were found in the average rates of gain in body weight between the corn-, wheat-, and barley-fed fryers and roasters. During the finishing period of 1937, the corn- and wheat-fed groups usually gained somewhat more than the barley-fed groups. In comparing the birds finished on the range with those finished in the battery, it is evident that the range-reared fryers receiving either corn or wheat gained appreciably more than the fryers finished in batteries. The reverse was true with those receiving barley. With the roasters, however, both the corn- and wheat-fed lots finished in batteries gained appreciably more than the corresponding lots finished on the range. There were no appreciable differences between the range and battery groups receiving barley, nor were there any appreciable differences in the amount of feed required to produce a unit of gain between the grains used during the finishing period.

From table 3, which gives dressed weights and grades, it is evident that the corn- and wheat-fed lots were heavier than the barley-fed lot in both years; there were no appreciable differences between the corn- and wheat-fed lots. The fryers receiving wheat on the range were appreciably heavier than those receiving wheat but confined to batteries for the 3-week finishing period. Of the roasters finished in 1937, those fed corn in the battery were heavier than those fed corn on the range. Other differences between battery- and range-finished birds were not significant. Although there appeared to be differences in the dressed grades, there was so much variation among the individuals receiving the same ration and treatment that these differences were not statistically significant.

TABLE 3.—*Average dressed weights, dressing percentages, and grades of dressed carcasses of fryers and roasters fed corn, wheat, and barley on range or in battery, 1936–37*

Type of bird, year, and ration	Average dressed weights (10 birds in each lot)			Ratio of drawn weights to live weights			Mean grade of carcasses for range and battery combined
	Range	Battery [1]	Range and battery combined	Range	Battery [2]	Range and battery combined	
	Grams	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	
Fryers (1937):							
Corn	[3] 1,162	1,140	[3] 1,151	[3] 71.1	[3] 70.9	[3] 71.0	1.8
Wheat	[4] 1,197	1,116	[4] 1,156	[4] 71.0	69.4	[4] 71.9	1.3
Barley	1,049	1,098	1,074	68.0	67.9	67.9	1.6
Roasters (1937):							
Corn	1,862	[2] 2,021	[3] 1,942	72.1	[5] 75.4	73.8	[5] 1.6
Wheat	1,865	[6] 1,840	[7] 1,852	73.4	[6] 71.2	72.3	1.9
Barley	1,798	[8] 1,726	[8] 1,762	72.2	71.9	72.0	2.0
Roasters (1936):							
Corn	[3] 2,094			[5] 68.2			[9] 2.4
Wheat	[10] 2,195			[5] 69.2			[9] 1.8
Barley	[4] 1,907			65.2			[9] 2.4

[1] The response of wheat-fed fryers was highly significantly greater on the range than in the battery; the response of barley-fed fryers was significantly greater in the battery than on the range; the response of corn-fed roasters (1937) was significantly greater in the battery than on the range.

[2] The response of the corn-fed roasters (1937) was highly significantly greater in the battery than on the range.

[3] Highly significantly greater response to corn than to barley.

[4] Highly significantly greater response to wheat than to barley.

[5] Significantly greater response to corn than to barley.

[6] Highly significantly greater response to corn than to wheat.

[7] Significantly greater response to corn than to wheat.

[8] Significantly greater response to wheat than to barley.

[9] Range-fed birds only.

[10] Significantly greater response to wheat than to corn.

Table 4 gives the distribution of fleshing in fryers and roasters. With the fryers, there was a higher percentage of light meat in the total edible meat of the wheat-fed birds than in that of the corn-fed birds. Similar differences were noted by Maw and Maw (*21*). The wheat-fed fryers graded somewhat higher than the corn-fed birds, as noted in table 3. There were no appreciable differences between the different groups in percentage of either dark meat or skin and subcutaneous fat. But the corn- and wheat-fed birds had a greater percentage of abdominal fat than the barley-fed fryers and roasters. This agrees with the work of Maw (*16, 17*) and Maw et al. (*18*). There were no appreciable differences between the corn- and wheat-fed fryer groups. Apparently those receiving barley and finished in the battery carried more abdominal fat than those receiving the same grain but finished on the range. The corn-fed roasters in 1937 carried more abdominal fat than the wheat-fed roasters. Especially was this true of the roasters finished in the battery. Differences between corn- and wheat-fed birds finished on the range were not appreciable. The birds receiving barley had more light meat than those receiving corn in 1936. The same was true in 1937, but the difference was not significant.

TABLE 4.—*Average percentage distribution of fleshing in the total edible portion of fryers and roasters fed corn, wheat, and barley on range or in battery, 1936–37*

Type of bird, year, and ration	Light meat			Dark meat			Skin and subcutaneous fatty tissue			Abdominal fatty tissue		
	Range[1]	Battery	Combined	Range	Battery	Combined	Range[2]	Battery	Combined	Range[3]	Battery	Combined
Fryers (1937):												
Corn	40.26	38.90	39.58	43.40	41.73	42.57	13.24	15.16	[4] 14.20	[4] 3.59	4.21	[5] 3.90
Wheat	[6] 43.56	41.90	[7] 42.73	42.45	41.36	41.90	12.25	12.96	12.61	[8] 1.74	3.78	[9] 2.76
Barley	[10] 43.61	40.49	[10] 42.05	44.51	43.27	43.89	11.60	13.71	[11] 12.66	[5] .28	2.55	1.41
Roasters (1937):												
Corn	40.80	38.90	39.84	43.00	43.20	43.10	12.72	12.20	12.46	[8] 3.51	[5] 5.74	[5] 4.62
Wheat	40.60	40.50	40.52	45.40	44.10	44.76	12.22	12.68	12.45	1.82	[12] 2.70	[12] 2.26
Barley	42.04	40.71	41.38	44.63	44.67	44.65	12.03	12.72	12.38	1.29	1.90	1.59
Roasters (1936):												
Corn	34.49	------	------	46.35	------	------	13.96	------	------	[11] 3.18	------	------
Wheat	36.84	------	------	45.27	------	------	14.42	------	------	[8] 3.45	------	------
Barley	[13] 39.04	------	------	47.38	------	------	12.60	------	------	.98	------	------

[1] The response of barley-fed fryers was significantly greater on the range than in the battery.
[2] The response of barley-fed fryers was significantly greater in the battery than on the range.
[3] The response of wheat-fed fryers was significantly greater in the battery than on the range; the response of barley-fed fryers was highly significantly greater in the battery than on the range.
[4] Significantly greater response to corn than to wheat.
[5] Highly significantly greater response to corn than to barley.
[6] Significantly greater response to wheat than to corn.
[7] Highly significantly greater response to wheat than to corn.
[8] Highly significantly greater response to wheat than to barley.
[9] Significantly greater response to wheat than to barley.
[10] Significantly greater response to barley than to corn.
[11] Significantly greater response to corn than to barley.
[12] Highly significantly greater response to corn than to wheat.
[13] Highly significantly greater response to barley than to corn.

Protein and ash analyses were not made on the edible portions of the cockerels grown in 1937 because it was felt that the protein and ash content probably would have no influence on the edible quality of the meat. The analyses made in 1936 of the 12 birds in each group show no significant differences among the different groups (table 5). This agrees with the report of Maw (*19*).

It should be emphasized that the standard errors of the averages for the protein, ash, moisture, and fat in the abdominal fatty tissue were very high because of the difficulty in getting sufficiently large samples from the birds. This is especially true of those receiving barley, in which group many of the birds had no abdominal fatty tissue.

TABLE 5.—*Average protein and ash content of light and dark meat and of fatty tissues of groups of 12 birds grown in 1936 and fed corn, wheat, and barley*

Ration	Light meat		Dark meat		Skin and subcutaneous fatty tissue		Abdominal fatty tissue	
	Protein	Ash	Protein	Ash	Protein	Ash	Protein	Ash
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Corn	24.37	1.10	21.04	1.17	21.78	0.65	4.02	0.23
Wheat	23.98	1.08	21.76	1.07	21.95	.63	3.77	.24
Barley	23.87	1.16	21.62	1.12	24.95	.80	6.22	.54

Table 6 gives the percentage of fat in the different edible portions of fryers and roasters. From these figures it is evident that the corn- and wheat-fed fryers and roasters had somewhat more fat in both the light and dark meats and more skin and subcutaneous fat than the birds fed barley. Differences between corn- and wheat-fed birds are not significant, a finding which agrees with that of Harshaw (*7*) and Maw (*17*), who report corn to be superior to other grains for fattening.

TABLE 6.—*Average fat content of edible portions of roasters and fryers (moisture-free) fed corn, wheat, and barley on range or in battery, 1936–37*

Type of bird, year, and ration	Light meat			Dark meat			Skin and subcutaneous fat			Abdominal fat		
	Range[1]	Battery	Combined	Range[2]	Battery	Combined	Range[3]	Battery	Combined	Range[4]	Battery	Combined
Fryers (1937):	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Corn	[5] 7.61	8.92	[5] 8.30	[6] 17.28	17.48	[5] 17.39	54.50	61.37	57.94	88.18	91.97	90.31
Wheat	[7] 6.67	9.77	8.14	13.59	17.18	15.29	55.74	56.34	56.03	87.90	91.00	89.67
Barley	4.47	7.05	5.76	10.61	16.33	13.47	52.94	54.28	53.57	[8]	88.28	
Roasters (1937):												
Corn	9.32	[5] 13.18	11.12	15.39	[5] 21.56	[5] 18.47	44.19	53.79	49.84	91.20	96.07	94.23
Wheat	8.77	10.90	9.84	13.04	17.39	[9] 15.33	44.24	48.31	46.50	85.46	93.50	91.03
Barley	8.44	9.95	9.24	12.76	16.08	14.42	39.79	48.90	44.59	96.46	94.42	95.30
Roasters (1936):												
Corn	[5] 9.14			[6] 21.66			[6] 56.75			83.01		
Wheat	[7] 9.06			[10] 18.66			[10] 56.82			91.69		
Barley	5.90			10.15			39.23			76.60		

[1] The response of barley-fed fryers was significantly greater in the battery than on the range.
[2] The response of barley-fed fryers was highly significantly greater in the battery than on the range; the response of corn-fed roasters (1937) was highly significantly greater in the battery than on the range; the response of wheat-fed roasters (1937) was significantly greater in the battery than on the range.
[3] The response of corn-fed roasters (1937) was highly significantly greater in the battery than on the range.
[4] The response of both corn-fed fryers and roasters (1937) was significantly greater in the battery than on the range.
[5] Significantly greater response to corn than to barley.
[6] Highly significantly greater response to corn than to barley.
[7] Significantly greater response to wheat than to barley.
[8] Insufficient abdominal fat present to permit chemical analysis.
[9] Significantly greater response to corn than to wheat.
[10] Highly significantly greater response to wheat than to barley.

In comparing battery and range methods of finishing, it is apparent that there was an increase in the percentage of fat in each of the four classes of edible meat when either fryers or roasters were finished in the battery. This was generally true regardless of the grain used. Significantly, and in general, the least fat was deposited in the barley-fed birds.

From table 7, it is apparent that the percentage of moisture present in the edible meat varied inversely with the percentage of fat, the barley-fed birds generally having somewhat more moisture than the corn-fed birds, with the wheat-fed birds intermediate. The inverse relationship between fat and moisture has been previously noted by Harshaw (*7*) and Holcomb and Maw (*8*).

TABLE 7.—*Average moisture content of edible portions of roasters and fryers fed corn, wheat, and barley on range or in battery, 1936–37*

Type of bird, year, and ration	Light meat			Dark meat			Skin and subcutaneous fat			Abdominal fat		
	Range[1]	Battery	Combined	Range[2]	Battery	Combined	Range[3]	Battery	Combined	Range	Battery	Combined
Fryers (1937):	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Corn	73.18	74.12	73.65	72.82	72.80	72.81	50.49	51.84	51.17	9.50	9.20	9.33
Wheat	74.19	73.69	73.95	73.49	72.95	73.23	[4] 52.31	49.39	[4] 50.93	15.07	9.80	12.06
Barley	74.34	73.90	74.13	74.01	72.24	73.13	[5] 57.89	51.99	[5] 55.09	([6])	11.59	------
Roasters (1937):												
Corn	72.51	70.55	71.49	73.26	71.97	72.62	50.80	43.20	46.30	9.30	7.10	8.04
Wheat	72.15	72.75	[7] 72.96	[7] 74.88	[7] 73.79	[7] 74.33	50.20	47.50	[4] 48.70	14.40	[8] 12.50	[7] 13.20
Barley	73.46	[9] 73.15	[9] 73.29	[5] 74.36	[5] 73.46	[9] 73.96	55.10	[9] 52.60	[9] 53.80	[9] 19.70	[5] 12.90	[8] 15.80
Roasters (1936):												
Corn	71.65	------	------	70.44	------	------	46.77	------	------	14.22	------	------
Wheat	[4] 71.61	------	------	[10] 70.73	------	------	[10] 47.59	------	------	13.06	------	------
Barley	[5] 73.07	------	------	[9] 73.65	------	------	[9] 57.48	------	------	20.51	------	------

[1] The response of corn-fed roasters (1937) was significantly greater on the range than in the battery.
[2] The response of the barley-fed fryers was highly significantly greater on the range than in the battery; the response of the corn-fed roasters (1937) was significantly greater on the range than in the battery; the response of wheat-fed roasters (1937) was highly significantly greater on the range than in the battery.
[3] The response of barley-fed fryers was significantly greater on the range than in the battery.
[4] Significantly greater response to barley than to wheat.
[5] Significantly greater response to barley than to corn.
[6] Samples insufficient for analysis.
[7] Highly significantly greater response to wheat than to corn.
[8] Significantly greater response to wheat than to corn.
[9] Highly significantly greater response to barley than to corn.
[10] Highly significantly greater response to barley than to wheat.

TABLE 8.—*Average distribution of edible uncooked meat and of fat and moisture in the edible meat on the left halves of carcasses of fryers and roasters fed corn, wheat, and barley on range and in battery, 1936–37*

Type of bird, year, and ration	Edible meat			Fat (moisture-free basis)			Moisture		
	Range[1]	Battery	Combined	Range[2]	Battery	Combined	Range[3]	Battery	Combined
Fryers (1937):	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Corn	67.8	72.3	70.0	[4] 21.0	[5] 23.9	[4] 22.4	68.1	67.5	67.8
Wheat	70.0	70.7	70.4	[6] 17.0	21.9	[7] 19.4	70.2	67.8	69.0
Barley	68.3	69.9	69.1	[8] 12.9	19.6	[6] 15.1	72.1	68.6	[9] 70.2
Roasters (1937):									
Corn	73.9	74.5	74.2	[5] 19.2	[4] 26.5	[4] 23.0	67.9	64.2	65.9
Wheat	74.3	73.4	73.8	16.5	[10] 20.7	[10] 18.7	70.1	68.4	[11] 69.2
Barley	72.8	72.6	72.7	15.3	19.2	17.3	71.0	[13] 70.0	[13] 70.3
Roasters (1936):									
Corn	78.8	------	------	[4] 23.8	------	------	64.3	------	------
Wheat	79.7	------	------	[7] 23.1	------	------	[13] 65.7	------	------
Barley	77.3	------	------	12.8	------	------	[13] 70.8	------	------

[1] The response of corn-fed fryers was significantly greater in the battery than on the range.
[2] The response of wheat-fed fryers was significantly greater in the battery than on the range; the response of barley-fed fryers was highly significantly greater in the battery than on the range; the response of corn-fed roasters (1937) was highly significantly greater in the battery than on the range; the response of wheat-fed roasters (1937) was highly significantly greater in the battery than on the range; the response of barley-fed roasters (1937) was significantly greater in the battery than on the range.
[3] The response of barley-fed fryers was significantly greater on the range than in the battery.
[4] Highly significantly greater response to corn than to barley.
[5] Significantly greater response to corn than to barley.
[6] Significantly greater response to corn than to wheat.
[7] Highly significantly greater response to wheat than to barley.
[8] Significantly greater response to wheat than to barley.
[9] Significantly greater response to barley than to corn.
[10] Highly significantly greater response to corn than to wheat.
[11] Significantly greater response to wheat than to corn.
[13] Highly significantly greater response to barley than to corn.
[13] Highly significantly greater response to barley than to wheat.

Table 8 gives the percentage of edible uncooked meat and the percentages of fat and moisture in the left halves of edible carcasses of

fryers and roasters. The wheat- and corn-fed birds did not differ appreciably in the amount of edible meat produced, but the barley-fed birds produced less than either group. This agrees with the finding of Maw et al. (*18*). There were no appreciable differences between any of the percentages of edible meat on the left half of the carcass.

The corn-fed fryers and roasters not only had the largest total quantity of body fat, but also the largest total percentage of body fat, followed in order by the wheat- and barley-fed birds. The same relationship has been previously noted by Maw et al. (*18*).

Table 9 gives the body measurements which were taken each year. The corn-fed fryers had a somewhat greater average breast length than the wheat-fed fryers. Other body measurements did not differ appreciably among the fryers of the different lots. In the 1937 experiments the average breast width 3 inches back from the tip and the heart girth were somewhat greater in the roasters receiving corn than in those receiving barley. The tibia anterior-posterior diameter was also larger in the corn-fed than in the barley-fed birds. In the 1936 experiments, the average breast-width measurements of the wheat-fed roasters were larger than those of either the corn- or the barley-fed roasters.

TABLE 9.—*Average body measurements of fryers and roasters fed corn, wheat, and barley, range and battery groups combined, 1936–37*

Type of bird year, and ration	Breast measurements				Shoulder width	Heart girth	Hip width	Femur length	Tibia measurements		
	⅝ of an inch from anterior tip	3 inches from anterior tip	1½ inches from edge	Length					Length	Anterior posterior	Lateral width
	Centimeters	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*
Fryers (1937):											
Corn	2.64	3.07	4.04	[1] 11.73	7.70	4.45	8.00	.....	.....	.....	.....
Wheat	2.62	3.20	3.91	[2] 11.33	7.90	4.42	8.08	.....	.....	.....	.....
Barley	2.74	3.12	3.99	11.33	7.67	4.34	8.03	.....	.....	.....	.....
Roasters (1937):											
Corn	[3] 2.77	[1] 3.35	[3] 4.83	13.89	[3] 9.76	[1] 5.93	9.59	12.52	17.09	[1] 5.22	3.63
Wheat	2.66	[4] 3.04	4.64	14.05	9.52	[2] 5.56	9.64	12.67	17.12	[5] 5.08	3.65
Barley	2.59	3.00	4.33	13.74	9.40	5.40	9.50	12.65	16.76	4.88	3.59
Roasters (1936):											
Corn	2.87	2.91	4.94	14.07	9.29	.....	.....	.....	.....	.....	.....
Wheat	[5] 3.02	[1] 3.21	5.07	[5] 14.66	[7] 9.68	.....	.....	.....	.....	.....	.....
Barley	2.69	2.68	4.87	13.54	[6] 9.08	.....	.....	.....	.....	.....	.....

[1] Highly significantly greater response to corn than to barley.
[2] Highly significantly greater response to corn than to wheat.
[3] Significantly greater response to corn than to barley.
[4] Significantly greater response to corn than to wheat.
[5] Significantly greater response to wheat than to barley.
[6] Highly significantly greater response to wheat than to barley.
[7] Significantly greater response to wheat than to corn.

It is evident from table 10 that there was more total body fat in the battery-finished birds than in the birds finished on the range. This was true of all groups regardless of the cereal grain used. There was a larger amount of total fat in the corn-and wheat- fed fryers and roasters than in the barley-fed birds, whether they were finished on the range or in batteries. The fryers and roasters receiving yellow corn had the largest amounts of fat in the light meat, dark meat,

skin and subcutaneous tissue, and the abdominal fatty tissue, followed closely by those receiving wheat; those receiving barley had appreciably less fat in each of the different classes of edible meats.

TABLE 10.—*Average weight and percentage distribution of fat in the total fat of fryers and roasters fed corn, wheat, and barley on range and in battery, 1936–37*

Type of bird, year, and ration	Weight of total fat in left half of carcass		Flesh fat				Skin and subcutaneous fat				Abdominal fat			
	Range	Battery	Range		Battery		Range		Battery		Range		Battery	
	Grams	*Grams*	*Grams*	*Per-cent*	*Grams*	*Per-cent*	*Grams*	*Per-cent*	*Grams*	*Per-cent*	*Grams*	*Per-cent*	*Grams*	*Per-cent*
Fryers (1937):														
Corn	71.7	83.3	36.0	50.2	37.6	45.0	25.1	35.0	32.5	39.0	10.6	14.8	13.3	16.0
Wheat	60.8	73.7	31.0	51.0	37.7	51.1	24.5	40.3	24.2	32.9	5.3	8.7	11.8	16.0
Barley	38.4	62.9	19.9	51.8	31.9	50.7	18.5	48.2	23.9	38.0	0	0	7.1	11.3
Roasters (1937):														
Corn	113.6	173.3	61.8	54.4	94.3	54.4	33.6	29.6	43.0	24.8	18.2	16.0	36.0	20.8
Wheat	96.7	121.2	55.8	57.7	70.4	58.1	31.9	33.0	35.8	29.5	9.0	9.3	15.0	12.4
Barley	85.7	103.7	51.8	60.5	60.5	58.3	27.1	31.6	33.3	32.1	6.8	7.9	9.9	9.6
Roasters (1936):														
Corn	162.1	------	88.8	54.8	------	------	55.0	33.9	------	------	18.3	11.3	------	------
Wheat	173.0	------	88.4	51.1	------	------	60.8	35.1	------	------	23.8	13.8	------	------
Barley	80.7	------	43.9	54.4	------	------	31.4	38.9	------	------	5.4	6.7	------	------

Relative to the distribution of the total body fat, it is apparent that as the percentage of abdominal fat increased in each group the percentage of fat in the other parts of the body decreased correspondingly. The abdominal cavity appears to be the last place in which fat is deposited. Many of the birds fed the barley ration had no abdominal fatty tissue. Had those receiving barley been fattened for a longer period than those receiving corn or wheat, however, the results might have been different. In the fryers, of all groups, from 45.0 to 51.8 percent of the total fat was deposited in the light and dark meats, 32.9 to 48.2 percent in the skin and subcutaneous fat, and 0 to 16 percent in the abdominal cavity. In the roasters, from 51.1 to 60.5 percent of the total fat was present in the light and dark flesh, 24.8 to 38.9 percent in the skin and subcutaneous tissue, and 6.7 to 20.8 percent in the abdominal fatty tissue. It is apparent that as fattening progresses fat continues to be deposited in the light and dark meats and in the skin as well as in the abdominal cavity. The amount of abdominal fatty tissue present gives a very good indication of the total amount of fat in the body.

Table 11 shows the relationships of the dressed weight to the total edible meat, the fat content, the alignment grade, and the index value. These figures are averages for the combined range and battery methods of finishing fryers and roasters. They show the general superiority in all respects of corn and wheat over barley for fryers and roasters. It will be noted that in 1937 there was appreciably more total edible meat on the carcass of the corn-fed roasters than on that of the barley-fed. The index value is also in close agreement and both differences are significant. A covariance analysis of the correlation between index value and the total edible meat on the left half of the carcass shows that for all the roasters produced in 1937 there was a positive correlation of 0.37, which is highly significant

and shows that this method of determing index value can be used in estimating the total edible meat present in the carcass, especially for roasters.

TABLE 11.—*Relationships of average carcass measurements of fryers and roasters fed corn, wheat, and barley (range and battery groups combined), 1936–37*

Type of bird, year, and ration	Dressed weight of whole carcass undrawn	Total edible meat on left half of carcass	Average fat content of left half of carcass	Alinement grade [1]	Index value
Fryers (1937):	*Grams*	*Grams*	*Grams*		
Corn	1,151	[2] 346	78	2.6	194
Wheat	1,156	[3] 348	68	2.1	194
Barley	1,074	310	47	2.8	190
Roasters (1937):					
Corn	1,942	[4] 623	143	1.6	[4] 267
Wheat	1,852	[5] 586	110	[6] 2.6	233
Barley	1,762	[7] 550	.95	[7] 3.2	[7] 218
Roasters (1936):					
Corn	2,094	[8] 676	162	2.6	232
Wheat	2,195	[9] 731	173	1.9	[8] 287
Barley	1,907	[8] 623	81	[9] 3.0	197

[1] On the basis of 1.0 being the top market grade and 4.0 being the lowest market grade.
[2] Highly significantly greater response to corn than to barley.
[3] Highly significantly greater response to wheat than to barley.
[4] Significantly greater response to corn than to wheat.
[5] Significantly greater response to wheat than to barley.
[6] Highly significantly greater response to wheat than to corn.
[7] Highly significantly greater response to barley than to corn.
[8] Significantly greater response to corn than to barley.
[9] Significantly greater response to barley than to wheat.

SUMMARY

When judged by the amount of feed required to produce a unit of gain in body weight of fryers during the growing period, wheat was most efficient, followed in order by barley and corn. In growing rations for roasters, the gain-feed ratio was practically the same for corn and wheat, but somewhat more barley was required for the same gain in body weight. In the finishing rations tested, corn, wheat, and barley ranked in this order of efficiency.

There were no appreciable differences in the average rates of gain in body weight between the corn-, wheat-, and barley-fed fryers and roasters receiving the growing rations in 1937. In 1936, however, those receiving barley grew less rapidly than those receiving corn or wheat. As finishing rations, yellow corn and wheat proved superior to barley for most of the groups, slightly better gains being made by the corn-fed group than by the wheat-fed.

The fryers receiving corn or wheat in the ration and finished on the range gained somewhat more in weight than the corresponding groups finished in batteries during the last 3 weeks; the reverse was true with those receiving barley. With the roasters both the corn- and wheat-fed groups finished for 2 weeks in batteries gained appreciably more than those finished on the range; there were no significant differences between the range and battery groups receiving barley in the ration.

The corn- and wheat-fed fryers and roasters had significantly more total edible meat on the carcasses than the birds receiving barley. The wheat- and barley-fed fryers and roasters had a somewhat higher percentage of light meat in the total edible meat than those receiving

corn. This may have been due to the fact that the corn group had the highest percentage of abdominal fatty tissue in the edible meat.

The corn-fed fryers and roasters showed a consistent tendency to deposit more fat in the light meat, dark meat, skin and subcutaneous fat, and the abdominal fatty tissue than the other two groups. They were followed in order by the wheat- and barley-fed groups, with significantly more fat in the carcasses of the corn-fed than in those of the barley-fed group.

In comparing battery and range methods of finishing, an increase was found in the percentage of fat in each of the four classes of edible meat in both fryers and roasters finished in the battery. Generally speaking, this was true regardless of the grain used. In general, the least fat was deposited in the barley-fed birds.

A tendency was noted toward an inverse relationship between the fat and moisture content of edible meat. Consequently, the range groups generally had a slightly higher moisture content than the battery groups, and the corn-fed birds a somewhat lower moisture content than either the barley- or the wheat-fed birds.

There was a significant positive correlation between the amount of edible meat on the carcass and the index value determined from the breast measurements taken.

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EFFECT OF CORN, WHEAT, AND BARLEY IN THE DIET ON THE FLAVOR OF FRIED AND ROASTED CHICKENS[1]

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INTRODUCTION

Research dealing with the preparation and cooking of poultry meat is comparatively new; consequently many of our present-day methods might well be tested with a view to improvement. There are also many unsolved problems connected with obtaining accurate estimates of flavor since such estimates are based on people's opinions. It is probable that much of the research work involving flavors which has been done in the past has not included a sufficiently large number of opinions and some of the judges on tasting committees have not been sensitive enough to detect differences in flavor.

EXPERIMENTAL PROCEDURE

PREPARATION OF CHICKENS FOR FRYING

The experiments herein reported were conducted in 1937. One-half of each of 10 Barred Plymouth Rock cockerels 17 weeks of age from each of 3 experimental rations were used. The average dressed weights of all groups was 3.13 pounds and represented those birds nearest the average weight for the group from which they were selected. The three growing rations used included 59 percent of either ground yellow corn, wheat, or barley added to the basal mash mixture, the same whole grain that was used in the mash being also fed ad libitum. The rations used and the methods of finishing are given in a previous report by Poley et al. (*12*).[3] About 72 percent of the ration consumed during the growing period consisted of either yellow corn, wheat, or barley. During the 3-week finishing period 62 percent of the cereal grain was consumed in the all-mash finishing ration which was mixed with water to a thin paste.

Feed was withheld but water was provided for 24 hours before killing time, when the birds were weighed. They were then dressed, chilled at 36° F., and the dressed weights taken. Several physical measurements of the dressed carcass were also taken, as previously reported (*12*). Table 1 gives the weights of the different parts into which the birds were divided, and also the percentage of live weight and dressed and drawn weights, for each part of the fryers and roasters. There have been several reports, including those by Bird (*1*), Harshaw (*5*), Maw (*9*), and Maw et al. (*10*), giving dressing percentages, chemical composition, and cooking percentages, but none involved a study of cooking percentages for fryers.

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[3] Italic numbers in parentheses refer to Literature Cited, p. 190.

TABLE 1.—*Average live and dressed weights, and dressing and cooking percentages of whole carcass and parts of fryers and roasters fed corn, wheat, and barley*

FRYERS

Item	Average dressed weights of carcasses and of parts of birds fed—			Proportion average dressed weight bore to—								
				Live weight of birds fed—			Dressed weight of birds fed—			Drawn weight (uncooked) of birds fed—		
	Corn	Wheat	Barley	Corn	Wheat	Barley	Corn	Wheat	Barley	Corn	Wheat	Barley
	Grams	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Average live weight	1,640.6	1,654.0	1,577.0	100.0	100.0	100.0	113.5	113.5	116.0	140.4	142.2	147.2
Average dressed weight	1,445.9	1,456.8	1,359.2	88.1	88.1	86.2	100.0	100.0	100.0	123.7	125.3	126.9
Average drawn weight	1,168.9	1,162.9	1,071.4	71.2	70.3	67.9	80.8	79.8	78.8	100.0	100.0	100.0
Inedible parts:												
Head	65.0	69.0	62.9	4.0	4.2	4.0	4.5	4.7	4.6	5.6	5.9	5.9
Shanks and feet	92.0	89.1	85.5	5.6	5.4	5.4	6.4	6.1	6.3	7.9	7.7	8.0
Entrails	120.0	125.2	136.6	7.3	7.6	8.7	8.3	8.6	10.1	10.3	10.8	12.7
Total	277.0	283.3	285.0	16.9	17.1	18.1	19.2	19.4	21.0	23.7	24.4	26.6
Edible carcass, uncooked: [1]												
Gizzard	40.4	33.4	36.2	2.5	2.0	2.3	2.8	2.3	2.7	3.5	2.9	3.4
Heart	6.6	6.4	5.9	.4	.4	.4	.5	.4	.4	.6	.6	.6
Liver	26.0	24.2	26.4	1.6	1.5	1.7	1.8	1.7	1.9	2.2	2.1	2.5
Neck [1]	91.3	94.5	77.9	5.6	5.7	4.9	6.3	6.5	5.7	7.8	8.1	7.3
Abdominal fat	24.2	20.9	10.5	1.5	1.3	.7	1.7	1.4	.8	2.1	1.8	1.0
Right half [1]	499.0	501.7	469.0	30.4	30.3	29.7	34.5	34.4	34.5	42.7	43.1	43.8
Left half [1]	481.4	481.8	445.5	29.3	29.1	28.2	33.3	33.1	32.8	41.2	41.4	41.6
Left half, uncooked:												
Light meat	136.2	148.9	132.1	8.3	9.0	8.4	9.4	10.2	9.7	11.7	12.8	12.3
Dark meat	146.7	143.2	135.7	8.9	8.7	8.6	10.1	9.8	10.0	12.6	12.3	12.7
Skin and subcutaneous fat	50.1	44.0	40.9	3.1	2.7	2.6	3.5	3.0	3.0	4.3	3.8	3.8
Bones	143.8	140.6	127.4	8.8	8.5	8.1	9.9	9.7	9.4	12.3	12.1	11.9
Moisture loss during dissection	4.6	5.1	9.4	.3	.3	.6	.3	.4	.7	.4	.4	.9
Total	481.4	481.8	445.5	29.3	29.2	28.3	33.3	33.1	32.8	41.3	41.4	41.6
Right half, uncooked	470.2	476.2	450.9	28.7	28.8	28.6	32.5	32.7	33.2	40.2	40.9	42.1
Right half, cooked:												
Light meat	113.7	121.8	106.6	6.9	7.4	6.8	7.9	8.4	7.8	9.7	10.5	9.9
Dark meat	113.1	114.8	110.9	6.9	6.9	7.0	7.8	7.9	8.2	9.7	9.9	10.4
Skin and subcutaneous fat	29.6	30.4	27.1	1.8	1.8	1.7	2.0	2.1	2.0	2.5	2.6	2.5
Drippings	21.2	19.3	19.9	1.3	1.2	1.3	1.5	1.3	1.5	1.8	1.7	1.9
Total edible	277.6	286.3	264.5	16.9	17.3	16.8	19.2	19.7	19.5	23.7	24.7	24.7

Bones and inedible	92.7	92.6	88.4	5.7	5.6	5.6	6.4	6.4	6.5	7.9	8.0	8.3
Total edible and inedible	370.3	378.9	352.9	22.6	22.9	22.4	25.6	26.1	26.0	31.6	32.7	33.0
Cooking loss	99.9	97.3	98.0	6.1	5.9	6.2	6.9	6.6	7.2	8.6	8.2	9.1
ROASTERS												
Average live weight	2,633.2	2,564.5	2,469.5	100.0	100.0	100.0	113.0	114.0	114.0	136.8	139.7	140.3
Average dressed weight	2,329.3	2,248.8	2,165.5	88.5	87.7	87.7	100.0	100.0	100.0	121.0	122.5	123.0
Average drawn weight	1,925.1	1,836.0	1,760.4	73.1	71.6	71.3	82.6	81.6	81.3	100.0	100.0	100.0
Inedible parts:												
Head	97.2	95.1	90.8	3.7	3.7	3.7	4.2	4.2	4.2	5.0	5.2	5.2
Shanks and feet	123.4	126.5	119.5	4.7	4.9	4.8	5.3	5.6	5.5	6.4	6.9	6.8
Entrails	182.1	192.7	187.3	6.9	7.5	7.6	7.8	8.6	8.6	9.5	10.5	10.6
Total	402.7	414.3	397.6	15.3	16.2	16.1	17.3	18.4	18.4	20.9	22.6	22.6
Edible carcass, uncooked: [1]												
Gizzard	46.9	47.4	49.0	1.8	1.8	2.0	2.0	2.1	2.3	2.4	2.6	2.8
Heart	13.0	11.7	11.0	.5	.5	.4	.6	.5	.5	.7	.6	.6
Liver	35.6	37.6	38.2	1.4	1.5	1.5	1.5	1.7	1.8	1.8	2.0	2.2
Neck [1]	151.8	146.7	143.5	5.8	5.7	5.8	6.5	6.5	6.6	7.9	8.0	8.2
Abdominal fat	56.1	29.3	17.2	2.1	1.1	.7	2.4	1.3	.8	2.9	1.6	1.0
Right half [1]	823.6	794.3	755.0	31.3	31.0	30.6	35.4	35.3	34.9	42.8	43.3	42.9
Left half [1]	798.1	769.0	746.5	30.3	30.0	30.2	34.3	34.2	34.5	41.5	41.9	42.4
Left half, uncooked:												
Light meat	243.9	235.9	226.9	9.3	9.2	9.2	10.5	10.5	10.5	12.7	12.8	12.9
Dark meat	275.5	261.6	249.5	10.5	10.2	10.1	11.8	11.6	11.5	14.3	14.2	14.2
Skin and subcutaneous fat	75.2	73.0	67.8	2.9	2.8	2.7	3.2	3.2	3.1	3.9	4.0	3.9
Bones	185.8	186.7	188.2	7.1	7.3	7.6	8.0	8.3	8.7	9.7	10.2	10.7
Moisture loss during dissection	17.7	11.8	14.1	.7	.5	.6	.8	.5	.7	.9	.6	.8
Total	798.1	769.0	746.5	30.5	30.0	30.2	34.3	34.1	34.5	41.5	41.8	42.5
Right half, uncooked	836.4	809.5	771.8	31.8	31.6	31.3	35.9	36.0	35.6	43.4	44.1	43.8
Right half, cooked:												
Light meat	294.6	291.7	272.6	11.2	11.4	11.0	12.6	13.0	12.6	15.3	15.9	15.5
Dark meat	213.6	201.7	197.5	8.1	7.9	8.0	9.2	9.0	9.1	11.1	11.0	11.2
Skin and subcutaneous fat	63.4	60.1	58.9	2.4	2.3	2.4	2.7	2.7	2.7	3.3	3.3	3.3
Drippings	31.4	15.8	23.6	1.2	.6	1.0	1.3	.7	1.1	1.6	.9	1.3
Total edible	603.0	569.3	552.6	22.9	22.2	22.4	25.8	25.4	25.5	31.3	31.1	31.3
Bones and inedible	160.2	154.6	152.3	6.1	6.0	6.2	6.9	6.9	7.0	8.3	8.4	8.7
Total edible and inedible	763.2	723.9	704.9	29.0	28.2	28.6	32.7	32.3	32.5	39.6	39.5	40.0
Cooking loss	73.2	85.6	66.9	2.8	3.4	2.7	3.2	3.7	3.2	3.8	4.6	3.8

[1] Includes bones.

The weights of edible meat which were taken included the gizzard, heart, liver, and abdominal fat. The weight of the neck, which included the skin, flesh, and bone, and the weight of the right and left halves of the edible carcass were also determined. Analyses were made on the left half of the carcass for both the fat and moisture content of the edible light meat, dark meat, skin and subcutaneous fat, and abdominal fat. The results of these analyses have been reported by Poley et al. (*12*). Figure 1 shows how the carcass was cut longitudinally through the vertebrae and sternum into two halves of approximately equal weight. The right half of each carcass was placed in an individual airtight oil-silk bag and stored at a temperature of 32° to 38° F. until cooking time. When cooked, the quantities of edible light meat, dark meat, skin and subcutaneous fat, and bones were determined. The light and dark meats were then scored for palatability by a committee of judges. Two halves from each of the three rations were fried on each of 5 days, over a 14-day period.

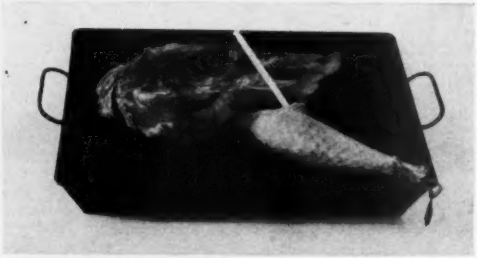

FIGURE 1.—The pan, rack, position of thermometer, and roaster during cooking.

For each chicken, 1 pound of fresh hydrogenated lard was placed in an iron chicken fryer (10 inches in diameter and 3 inches deep) and heated by electricity to 175° C. This was just enough fat to bubble up over the chicken and give all the surfaces a golden-brown crust. Thermometers were placed in the thigh and breast pieces, but since there was insufficient flesh to protect the thermometer bulbs from the hot fat, the temperature readings were unreliable and higher than the "doneness" of the meat would indicate; so each chicken was cooked in the uncovered pan for 30 minutes. The temperature of the fat usually dropped about 30° from the original reading within 5 minutes after the chicken was placed in the fryer and remained at about 145° throughout the rest of the cooking period. The average weights of the right halves of the 10 chickens selected from each ration were 470 gm. for the corn-fed, 476 gm. for the wheat-fed, and 451 gm. for the barley-fed birds. The half to be fried was cut into two parts, dark and light meat. The former included the tibia, metatarsus, and flesh over the ilium (often called the "oyster"); the latter included the breast muscle and wing. No seasoning, flour, or other substance that might affect the flavor of the meat was used. The skin was not employed in the flavor studies, although it was left on the carcass until frying was completed.

PREPARATION OF CHICKENS FOR ROASTING

Ten 26½-week-old Barred Plymouth Rock cockerels were selected from each 17-bird group finished. The average weights of these birds (table 1), were closest to the average weight of the group from which they were taken. The birds had received the same growing and finishing rations that were fed to the fryers and were selected in the same manner.

About 82.9 percent of the ration consumed by the corn-fed group during the growing period consisted of yellow corn. Eighty-nine percent of the ration consumed by the wheat-fed group was wheat, and 83.6 percent of that consumed by the barley-fed group was barley. During the 2-week finishing period, 62 percent of either yellow corn, wheat, or barley was consumed, as this percentage of grain was included in the all-mash finishing ration which was mixed with water to a thin paste just before feeding.

The roasters were killed after being deprived of feed for 24 hours, with water to drink the first 12 hours, and then were dissected. The different parts into which the carcass was separated are given in table 1. The left half was used for chemical analysis and the right half for palatability studies, the same method being used as with fryers.

The average dressed weights of the 10 halves of the birds from each ration were 2,329.3, 2,248.8, and 2,165.5 gm. respectively for the corn, wheat, and barley-fed roasters. The birds were roasted with the skin side down on racks in pans (fig. 1) in an automatically controlled electric oven large enough for six pans. A meat thermometer was inserted in the thigh muscle and the temperature allowed to reach 92° C. The oven temperature was maintained at about 149° C. Niles (*11*) reported that the internal temperature of the thigh should reach 85° C. Moreover, she reported that the flavor of chicken roasted in an uncovered pan was preferable, although the skin was dry as compared to that which was roasted in a pan covered for part of the time. Lowe (*7*) also reported that the internal temperature of the thigh muscle of chicken should reach 85°. In the present experiments, the flesh did not appear sufficiently cooked at 85°, so 92° was preferred. Maw (*8*) used a constant oven temperature of 191° C. for roasting chicken.

Two oven thermometers were used inside of the oven to check the temperatures, which were read every 10 minutes. Two chickens from each of the rations were roasted at one time on each of 5 days within a 10-day period.

As soon as the temperature of the thigh muscle reached 92° C. the carcass was taken from the oven and weighed. The skin was then removed and samples taken for palatability studies. The same method used in determining the weights of the bones and edible flesh of fryers was employed. The residue included the juice which dripped from the carcass during roasting and the juice which drained from the carcass when the skin and subcutaneous fat were removed and the leg and thigh were separated from the remainder of the carcass.

FLAVOR STUDIES

Palatability studies were made on both the light and dark meats, and consisted of scoring as to intensity and desirability for both fryers and roasters. The intensity measurements were subdivided into aroma, flavor, juiciness, texture, and tenderness. Texture was judged only for the roasters. Desirability was subdivided into aroma, flavor, and juiciness. These palatability factors were evaluated from 1 to 7, according to the increasing intensity and desirability of each factor. This was done independently by individuals of a committee of nine judges according to a grading chart for cooked meat similar to the one used in the National Cooperative Project of Meat Investigations,[4] except that no consideration was given to the intensity and desirability of fat flavor. Throughout the test, each judge was served the same cross section of muscle from each chicken, with samples taken from both light and dark meats. The samples were cut as quickly as possible at right angles to the length of the muscle, and served while still warm to each judge. The judges were allowed water and white bread but no butter. No salt or other seasoning was used. As soon as the judges had completed the scoring of light and dark meats from one carcass, they were given samples from each of the five remaining carcasses. The six samples (12 portions) were distributed at random among the judges. Consequently the judges had no knowledge of the classification of the birds from which the samples were taken.

TESTING THE JUDGES

Crocker and Platt (*3*) state that there are four commonly accepted kinds of taste buds which give the four primary tastes, sweet, sour, salty, and bitter. Since it has been demonstrated by a number of workers (*2*, *4*, *13*) that considerable variation exists among individuals in their response to taste and smell, and some people cannot satisfactorily detect certain flavors, tests were made to determine the sensitivity and consistency of response of the nine judges who assisted in the study. The method used was similar to the one described by King (*6*), with one modification; namely, the solutions of sucrose (sweet), sodium chloride (salt), lactic acid (sour), and caffeine (bitter) were given in random order. This was done to eliminate the possibility of psychological reactions to the solutions of low concentration. The solutions and concentrations used are shown in table 2.

TABLE 2.—*Solutions and molar concentrations of solute used in determining the sensitivity and consistency of response of the nine judges*

Solution No.	Sucrose	Sodium chloride	Lactic acid	Caffeine
	Moles	*Moles*	*Moles*	*Moles*
1	0.0005	0.0010	0.0001	0.0001
2	.0010	.0020	.0002	.0002
3	.0025	.0050	.0005	.0005
4	.0050	.0100	.0010	.0010
5	.0100	.0500	.0025	.0025
6	.0250	.1000	.0050	.0050
7	.0500	.2000	.0100	.0100
8	.1000	.2500	.0250	.0250
9	.1500			

[4] U. S. BUREAU OF ANIMAL INDUSTRY. A STUDY OF THE FACTORS WHICH INFLUENCE THE QUALITY AND PALATABILITY OF MEAT. Rev. ed., 76 pp. 1927.

Without a knowledge of either the kind or the concentration of the solution used, each judge was required to identify the solution and estimate its concentration. The following numbers and descriptive terms were employed: 0, No taste; 1, very faint; 2, faint; 3, easily distinguishable; 4, strong; 5, very strong. The judges were given two tests approximately 6 weeks apart, the same procedure being used in both.

The ability to recognize a low concentration of a solution as well as to estimate consistently the intensity of a taste are essential to good judging of flavor. The range of molar concentrations for the judges' threshold of taste as well as the median molar concentration of the solutions are given in table 3. (The threshold value of taste is the lowest molar concentration at which a taste can be identified. This is qualified by the requirement that all higher concentrations be accurately identified).

The values shown in table 3 compare favorably with the values determined by King (*6*). The frequency distribution of threshold values for the nine judges approximates a normal curve. One judge was found to have uniformly low threshold values for all substances, one judge had uniformly high threshold values, two judges had uniformly average threshold values, and the threshold values of the remaining judges were mixed.

TABLE 3.—*Median and range of taste thresholds of the nine judges*

Substance	Solution concentration at threshold		Substance	Solution concentration at threshold	
	Median	Range		Median	Range
	Moles	*Moles*		*Moles*	*Moles*
Sucrose	0.0153	0.0025–0.05	Lactic acid	0.0025	0.0002–0.005
Sodium chloride	.0550	.005 – .20	Caffeine	.0019	.001 – .005

The term "consistency" denotes the ability of a judge to reproduce his estimates of taste intensity. To determine the consistency of a judge, the difference in the identification numbers of the solutions representing his threshold values on test 1 and test 2 were used. For example, if on test 1 a judge first identified sucrose (threshold value) at a concentration of 0.0010 mole, and on test 2 he identified sucrose at a concentration 0.0025, his consistency number for sucrose would be $3-2=1$. To further estimate the consistency of a judge, the difference in the numbers of the solutions representing his choice of "easily distinguishable taste" was used. The results are shown in table 4. An examination of the distribution of consistency numbers in table 4 shows that the judges were able to reproduce responses more accurately at the easily distinguishable than at the threshold level of taste. This observation substantiates the finding of King (*6*). The average consistency number for the committee of judges at the threshold level of identification was 1.4 (range 0.6–2.0) and for the easily distinguishable level of identification 0.99 (range 0.3–1.7). These consistency numbers compare favorably with those of the 14 judges selected by King from a group of 64 judges.

TABLE 4.—*Consistency numbers of the nine judges of flavor*

Average consistency numbers	"Threshold" distribution	"Easily distinguishable" distribution
0.0–0.3	0	1
.3– .9	3	4
.9–1.5	4	4
1.5–2.1	2	0

To summarize, it is believed that the judges who assisted in these meat-tasting studies represented an average or better than average group as judged by the data of King (*6*). It is, therefore, assumed that their estimates of meat quality are reliable.

STATISTICAL ANLAYSES

Statistical treatment included an analysis of variance. *F* values were calculated and compared to the minimum *F* value necessary for significance as reported by Snedecor (*14*, *table XXXV*). *F* values necessary for odds of 19 to 1 (significant) and 99 to 1 (highly significant) are reported. The *F* value was determined by the following formula: $F=\frac{\text{larger mean square}}{\text{smaller mean square}}$. For example, for intensity of aroma of the light-meat samples (table 6), an analysis of variance of the palatability scores was made as shown in table 5. Where the *F* value approached significance, a more complete analysis was made with a view to subtracting out the sum of squares between birds and the sum of squares between samples. This analysis did not raise any of the mean differences to the level of high significance (odds 99 to 1).

TABLE 5.—*Analysis of variance of the palatability score for aroma of light meat in table 6*

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F* value
Total	219	476.10		
Between means of feed	2	.68	0.34	0.2
Within feeds	217	475.42	2.19	

EXPERIMENTAL RESULTS

FRYERS

The dressing percentages of the different parts into which the carcasses were separated are given in table 1. The table shows no appreciable differences in dressing percentages between the birds receiving the different grains in their rations. However, there was a tendency for the barley-fed group to have slightly lower percentages of their live weight as dressed and drawn weights than the corn-and wheat-fed birds, which were about equal. There was also a slightly higher percentage of inedible and a lower percentage of total edible meat on the carcasses of the barley-fed fryers as compared to those receiving either corn or wheat, although none of these differences were significant.

There were no appreciable differences between the cooking losses of either the barley- or the wheat-fed birds as compared with those of the birds receiving yellow corn in the ration. There was slightly less cooked light meat, dark meat, and skin and subcutaneous fat on the barley-fed fryers than on the fryers receiving the other grains. This is to be expected in view of the lower body weights of these barley-fed birds. It should be noted that the percentages which are given for the uncooked and cooked parts of the left and right halves are based only on half of the carcass. In order to determine the percentage of either the edible meat or bones for the whole carcass, the following formula may be used:

$$A=2\frac{B}{C}$$

Where A=the percentage of either live weight, dressed, or drawn weight; B=the average weight of either the light meat, dark meat, skin and subcutaneous fat, or bones; and C=the average weight of the birds either alive, dressed, or drawn. Thus, the percentage of edible light meat on the whole dressed carcass for the corn-fed fryers would be calculated as follows:

$$\text{Percentage of edible light meat}=\frac{2\times 136.2}{1{,}445.9}=18.8 \text{ percent.}$$

With the corn-fed fryers, it may be calculated that 19.4 percent of the whole uncooked drawn carcass was cooked light meat, while the same percentage was dark meat, with 5 percent skin, 3.6 percent drippings (total 47.4 percent edible), and 15.8 percent cooked bones and inedible. The cooking loss based upon the drawn weight of the uncooked carcass was 17.0 percent. It should be kept in mind that these percentages include only the two halves. The neck, abdominal fat, and giblets were not cooked. The two halves, however, represented 81.4 percent of the edible carcasses of the birds receiving yellow corn. The cooking percentages for those receiving barley were approximately the same as for the corn-fed group.

TABLE 6.—*Mean palatability scores for light and dark meat of fryers and roasters fed corn, wheat, and barley*

FRYERS

Ration	Birds	Intensity factors: Aroma		Intensity factors: Flavor		Intensity factors: Tenderness		Intensity factors: Juiciness		Desirability factors: Amora		Desirability factors: Flavor		Desirability factors: Juiciness	
		Light [1]	Dark [1]	Light [2]	Light [3]	Light [3]	Dark [4]	Light [5]	Dark [5]	Light [6]	Dark [6]	Light [7]	Dark [8]	Light [9]	Dark [10]
	Number														
Corn	10	3.87	4.30	4.26	4.54	5.09	5.20	3.53	4.03	3.63	4.08	3.46	4.21	3.61	4.06
Wheat	10	3.76	3.89	4.50	4.38	4.67	5.19	3.61	4.12	4.03	4.10	4.18	4.47	4.00	4.31
Barley	10	3.81	4.07	4.30	4.44	5.19	5.05	3.54	3.98	3.75	3.86	4.11	4.10	3.71	4.16
F value [11]		.2	2.8	1.6	2.7	1.5	.5	.2	.5	1.2	.2	2.1	.5	.5	.5

See footnotes at end of table.

TABLE 6.—*Mean palatability scores for light and dark meat of fryers and roasters fed corn, wheat, and barley*—Continued

ROASTERS

Ration	Birds	Intensity factors										Desirability factors					
		Aroma		Texture		Flavor		Tenderness		Juiciness		Aroma		Flavor		Juiciness	
		Light [12]	Dark [13]	Light [13]	Dark [13]	Light [14]	Dark [8]	Light [15]	Dark [4]	Light [16]	Dark [17]	Light [18]	Dark [19]	Light [20]	Dark [21]	Light [22]	Dark [23]
Corn	16	4.59	4.76	5.81	5.33	5.24	5.08	6.16	5.41	5.10	4.90	5.13	4.93	5.29	5.01	5.20	4.82
Wheat	17	4.79	4.91	6.00	5.30	5.25	5.01	6.07	5.15	5.09	4.73	5.33	4.92	5.30	4.93	5.11	4.84
Barley	15	4.69	4.73	5.85	5.30	5.14	4.94	6.06	5.04	5.26	4.92	5.03	4.64	5.18	4.47	5.23	4.78
F value [24]	------	.7	.7	1.1	.5	.6	.1	.3	2.2	.3	.6	1.4	.9	.1	2.3	.1	.3

[1] Perceptible to slightly pronounced aroma.
[2] Slightly to moderately pronounced flavor.
[3] Slightly tough to moderately tender.
[4] Moderately tender to tender.
[5] Perceptible to slightly rich juciness.
[6] Neutral to slightly desirable aroma.
[7] Neutral to slightly desirable flavor.
[8] Slightly to moderately desirable flavor.
[9] Dry to slightly dry.
[10] Slightly rich to moderately rich in juiciness.
[11] For the difference between the means in any column to be significant the *F* value entered below the column must equal or exceed 3.04; for the difference to be highly significant the *F* value must equal or exceed 4.71.
[12] Slight to moderately pronounced aroma.
[13] Moderately fine to fine texture.
[14] Moderately pronounced to pronounced flavor.
[15] Tender to very tender.
[16] Moderately rich to rich juiciness.
[17] Slight to moderately rich juiciness.
[18] Moderately desirable to desirable aroma.
[19] Slight to moderately desirable aroma.
[20] Moderately desirable to desirable flavor.
[21] Slight to moderately desirable flavor.
[22] Moderately juicy to juicy.
[23] Slightly dry to moderately juicy.
[24] Significant *F* value, 3.21; highly significant *F* value, 5.11.

Palatability scores given in table 6 show that there were no significant differences in the intensity or desirability factors in respect to aroma, flavor, tenderness, or juiciness of the light and dark meats from the fryers receiving either corn, wheat, or barley as the principal constituent of the ration. The greatest differences in the judges' scores are found in (1) the intensity of aroma of the dark meat of the corn-fed fryers, which was scored slightly higher than that of either the wheat- or barley-fed fryers, and (2) tenderness, which was scored slightly higher in the corn-fed than in the wheat-fed. Of the desirability factors, the aroma and juiciness of the light meat of the wheat-fed groups were scored slightly higher than for either the corn- or barley-fed birds. The flavor of the light meat was also scored a little higher with those receiving corn. None of these differences was significant, however.

It is worthy of note that Satorius and Child (*13*) found with beef that there was a high positive correlation between judges' tenderness scores and shear force required to cut muscles. This fact indicates that a judge can estimate tenderness with accuracy without the aid of a mechanical shearing device. No positive correlation, however, was found between the quantity of press fluid, or ether extract of fat, and the palatability-juiciness character as scored by the judges. Other

palatability factors such as flavor-aroma which stimulate the flow of saliva were found to be more important in affecting the judges' score of juiciness than the fat content or the amount of press fluid.

ROASTERS

The dressing and cooking percentages of the edible and inedible parts of the carcasses of roasters were not appreciably different whether the birds received yellow corn, wheat, or barley, as will be noted from table 1. As with the fryers, the average dressed weight was appreciably less for the barley-fed groups than for the corn-fed. The birds receiving wheat also weighed less than those receiving corn. The percentage dressed weight of the live weight was somewhat greater with the birds receiving corn, as would be expected with slightly better fleshing. The percentage of total inedible parts was also slightly higher and the percentage of edible meat slightly lower in these birds than in those receiving either barley or wheat. There were no appreciable differences between the percentages of edible cooked light flesh, dark flesh, and skin, although the corn-fed birds had somewhat larger amounts, followed in order by those fed wheat and barley. There was a somewhat greater residue of drippings and juice from the corn-fed birds, less from the barley-fed, and least from the wheat-fed. The inedible portion was slightly higher in the corn group, but the percentages were practically the same for all groups. Cooking losses varied a great deal within the groups, but seemed slightly higher with those receiving wheat. All of these calculations are based upon half of the carcass and do not include the giblets, abdominal fat, or neck. To calculate the percentages for the whole carcass, the formula given for the fryers is used. Accordingly, 30.6 percent of the drawn weight was light meat in the corn-fed roasters while 22.2 and 6.6 percent was dark meat and skin respectively (total 59.4 percent edible), with 3.2 percent residue or drippings and 7.6 percent cooking loss by evaporation. These percentages might be expected if roasters are cut in half for roasting; naturally they do not indicate the percentages that would be obtained if other roasting methods were used.

The palatability scores for roasters given in table 6 show that there were no significant differences in either the intensity or desirability factors as regards aroma, flavor, tenderness, and juiciness of the light and dark meats from the birds receiving corn, wheat, or barley as the principal constituent of the ration. The differences between the average scores of the birds in the different roaster groups were even smaller than the differences between the fryers on the different rations.

The greatest differences between the average scores of the judges were in tenderness and desirability of flavor of the dark meat. The dark meat of the corn-fed roasters was considered slightly tenderer and of better flavor than that of the barley-fed roasters. In general, there was considerable variation in the judges' scores, and therefore agreement could not be reached on whatever differences might have existed in the palatability of these roasters. It should be kept in mind that, although all these birds were fed, managed, dressed, drawn, chilled, and roasted under uniform conditions there may have been some differences due to handling that affected palatability. For instance, if the bird did not bleed completely when killed, any blood remaining in the tissues might, after a few days holding, taste rather strong and affect the judges' score of the flesh. However,

precautions were taken in an effort to get as complete drainage of the blood as possible.

CONCLUSIONS

There were no significant differences between the dressing and cooking percentages of the fryers and roasters receiving either wheat or barley as the principal constituent of the ration and those receiving yellow corn.

A committee composed of nine judges could detect no appreciable differences in aroma, flavor, juiciness, or tenderness of either the light or dark meat from fryers and roasters receiving either corn, wheat, or barley in the growing and finishing rations.

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THE INFLUENCE OF INTENSITY OF EGG PRODUCTION UPON INFERTILITY IN THE DOMESTIC FOWL[1]

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INTRODUCTION

The eggs produced by breeding flocks of apparently normal hens under systems of good management include various proportions which are infertile, the number sometimes ranging as high as 30 percent (*15*)[2] of the total incubated. With small numbers of birds or under adverse conditions much larger proportions of the eggs laid may be infertile. The causes of much, perhaps most, of this infertility remain unknown and additional knowledge concerning their control is essential to an adequate understanding of avian reproduction and to the diminution of such economic losses as now result from the incubation of infertile eggs.

The objects of the present experiment were (1) to determine whether degree of infertility is influenced by the intensity of egg production in the fowl, and (2) to study the bases for such a relationship if it exists.

MATERIALS AND METHODS

During the 5-year period, 1935 to 1939, more than 1,200 females and more than 100 males representing several different strains of White Leghorns were used for this study. These hens do not constitute a random sample since those previously shown by individual performance to be poor layers were not placed in the breeding pens. They are, therefore, comparable to better-than-average commercial breeding flocks and are excellent material for study of the practical aspects of infertility.

A study of this nature is so complicated by various causes of infertility which are unknown or cannot be standardized, that the discovery of new facts bearing on the problem is possible only by the use of very large numbers of birds and eggs. Even with the large numbers considered in this study, a very few hens with excellent records of production have caused disconcerting irregularities in the results because all, or nearly all, of their eggs were infertile from causes unknown, but probably not related to intensity of egg production. Such hens have nevertheless been included in this study because there is apparently no level of infertility above which it can be said that intensity of egg production exerts no influence.

Artificial illumination was not used in the breeding pens until the January preceding the incubation season (February, March, and April) except in special matings reported in table 5. Matings were made in pens having 1 male with 12 to 16 females.

[1] Received for publication January 6, 1940.

[2] Italic numbers in parentheses refer to Literature Cited, p. 205.

The number of eggs laid, as given in tables 1, 2, and 3, is assumed to equal the number of eggs incubated. It is therefore subject to the usual small error in trap-nesting and marking the eggs, plus an error due to loss and breakage prior to incubation. Since 24,000 to 40,000 eggs are considered in tables 1 to 3, it is believed that such errors would be distributed by chance and therefore not materially influence results, except perhaps in measurements involving size of clutch.

Infertility was determined by candling the eggs (tables 1–4), or by appearance of the germinal disk of the broken egg after 18 to 25 hours of incubation. By neither of these methods is one able to distinguish between infertile eggs and ones with embryos dead at very early stages, but there is a practical limit to the embryonic age at which fertility can be routinely determined. With the large number of hens involved in this study such errors are assumed to occur at random.

EXPERIMENTAL RESULTS

RELATION BETWEEN FERTILITY AND INTENSITY OF PRODUCTION

The period studied each year extended from February 1 to April 30, the normal incubation season. By such a restriction one avoids the extreme fluctuation in the rate of production from season to season. The frequent occurrence of such variations suggests that any accurate measure of intensity must be based upon the egg production during a relatively short period of time. Individual incubation records for each hen were obtained for eggs laid during February, March, and April of 1935 to 1939, inclusive, and were studied by the use of the following three measures of intensity of egg production: (1) The number of eggs laid during a specified period of 6 weeks; (2) the number of eggs laid during each week of the incubation period; and (3) the number of eggs laid per clutch (number of eggs laid on consecutive days).

Number of Eggs Laid During a 6-Week Period

The number of eggs laid during a 6-week period was tabulated for each of 856 females. During the 5 years this 6-week period fell between February 22 and April 14. Slight differences occurred within these limits from year to year because of shifts in the hatching schedule. The periods did not include the first and last hatches of the season, and periods for all hens during a given year were identical. Those hens which did not lay during each of the 6 weeks were not included, because a true measure of their intensity would not have been obtained.

Egg production by different individuals during the 6-week period ranged from 13 to 40 eggs, the mode falling between 29 and 33 eggs. It is clear that those hens which laid the greater number of eggs laid relatively fewer infertile eggs (table 1). In each of the 5 years, eggs from those hens which laid from 13 to 22 eggs during the 6-week test period included the highest proportion of infertiles. In 3 of the 5 years, those hens which laid the most eggs (32 to 40) had proportionately fewer infertile eggs than did the poorer layers. When the percentages for the 5 years are averaged, the group of females which laid the fewest eggs is shown to have nearly twice as many infertiles (24.4 percent) as the birds in the group of best layers (13.0 percent). Because there are wide differences in the proportions infertile among eggs laid during different years, unweighted averages of the percentages obtained

during the different years have been used in this study. This practice was employed to avoid giving unequal weight to those factors that influence infertility differently in different years.

TABLE 1.—*The proportion of infertile eggs produced by three groups of hens that laid 13–22, 23–31, and 32–40 eggs, respectively, during a 6-week period, 1935–39*

Year	Data for hens laying—								
	13 to 22 eggs in 6 weeks			23 to 31 eggs in 6 weeks			32 to 40 eggs in 6 weeks		
	Hens	Eggs laid	Infertile eggs	Hens	Eggs laid	Infertile eggs	Hens	Eggs laid	Infertile eggs
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
1935	16	320	26.2	102	2,860	18.2	55	1,844	9.9
1936	11	208	41.8	73	2,069	26.8	68	2,301	18.4
1937	34	657	17.8	125	3,460	12.4	41	1,367	11.2
1938	10	200	12.0	93	2,674	8.0	48	1,597	8.8
1939	15	288	24.3	104	2,922	12.6	61	2,046	16.4
Total	86	1,673	[1] 24.4	497	13,985	[1] 15.6	273	9,155	[1] 13.0

[1] Unweighted average of the percentages for the 5 years.

NUMBER OF EGGS LAID DURING A 1-WEEK PERIOD

The number of eggs laid during 1 week is a good measure of intensity because such a short period of time excludes some error resulting from fluctuation of intensity during a longer period. Such error would be important if intensity of egg production influenced fertility in those eggs currently produced.

The incubation record of each hen was divided into weekly periods, each of which was assigned to one of seven groups according to the number of eggs (one to seven) laid during that week. The first week of the incubation record was omitted in each case in order to insure adequate time for mating after the males were placed in the pens, and some of the later hatches were omitted to avoid lack of uniformity in the length of the hatching season. Eggs included in these data were laid during February, March, and April. A separate study of the data for 1937 gave no indication that seasonal differences in infertility (*14*) influence the distribution of infertility shown in table 2.

TABLE 2.—*The proportion of infertile eggs produced by 1,084 hens during weekly periods in which from 1 to 7 eggs were laid, 1935–39*

Year	Infertile eggs produced by hens laying the indicated number of eggs during each week							Weighted averages (all weeks)
	1	2	3	4	5	6	7	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1935	32.5	24.2	25.0	17.9	15.5	14.1	9.2	16.2
1936	37.9	35.1	27.6	27.7	22.0	20.0	18.4	22.1
1937	31.9	23.9	12.2	16.0	11.2	10.4	3.3	12.0
1938	23.3	20.8	17.4	12.4	9.8	6.3	16.3	10.0
1939	30.3	22.6	15.7	13.6	10.8	13.7	11.7	12.9
Average (unweighted)	31.2	25.3	19.6	17.5	13.9	12.9	11.8	14.7
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Total number of eggs	212	746	2,073	6,036	14,490	11,442	1,533	36,532

The proportion of infertile eggs in each of the seven groups in each of the 5 years is shown in table 2. In each year the highest proportion of infertiles was found in the group of eggs laid at the rate of only one per week, whereas the smallest proportion was found in the groups that were laid at the rapid rate of five or more eggs per week. It can be seen that there are wide differences from year to year which are probably the result, directly or indirectly, of environmental changes, but the averages of the percentages of infertile eggs in the groups which

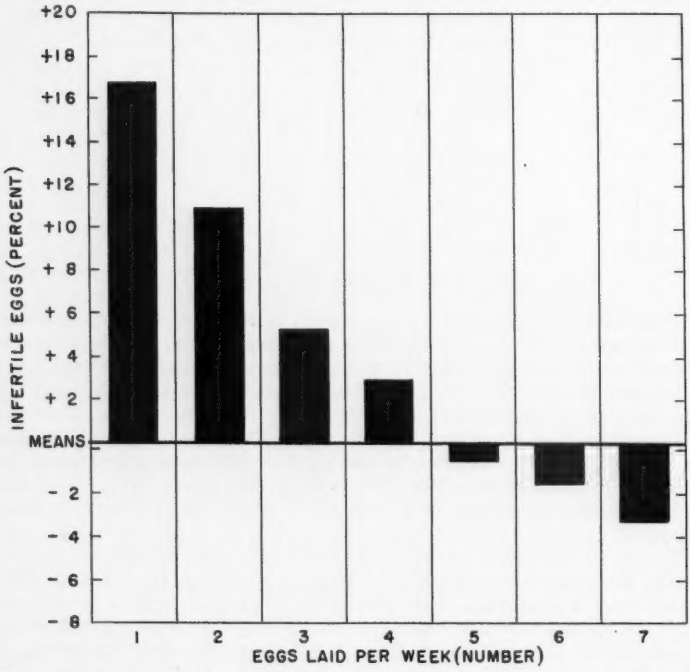

FIGURE 1.—The proportion of infertile eggs in groups of eggs which were laid at rates of from one to seven per week. Each column represents the average of the deviations from the mean for each of the 5 years (see text). The total number of eggs included in each group is shown in table 2.

were laid at different rates show a striking and consistent decline as the rate of egg production increases. In the group of eggs laid at the rate of only one per week, the proportion of infertiles (31.2 percent) is nearly three times as high as in the eggs laid at the rate of seven per week, where it was only 11.8 percent.

Because the percentages of infertility in the different years were not uniform, it is questionable whether the data for all 5 years should be combined. To overcome this difficulty and to permit comparisons of infertility in the groups of eggs laid at different rates the following procedure was adopted. To remove the differences between years the percentage infertile (weighted average) among all eggs for any 1 year

was calculated and used as a base line. This percentage was then subtracted from the percentage of infertiles that year in each of the seven groups of eggs which were laid at rates of one to seven, respectively, per week. This was done with the data for each of the 5 years. Finally, the plus and minus differences thus obtained for corresponding groups (one to seven eggs) during each of the 5 years were averaged (unweighted) to show the average deviation in percent from the five means in the proportion of infertle eggs in each of the seven groups (fig. 1).

This combination of the 5 years' data shows that the proportion of infertiles was less, by 19 percent of the total eggs, among those laid at the rate of seven a week than among those laid at the rate of one a week. Since among all eggs studied less than 15 percent were infertile (table 2) the columns in figure 1 further indicate that the proportion of infertiles among eggs laid at the rate of one a week was more than twice that found among eggs laid at the rate of five to seven a week.

It must be remembered that nearly every hen is represented in two or more of the groups in figure 1 and that here the influence of intensity of production upon fertility is more accurately measured than in the longer periods considered in table 1, where all eggs from a given hen were grouped together regardless of changes in the intensity of production. It is important to note that in this phase of the study greater extremes in the intensity of production (14 to 100 percent) were measured than are analyzed in table 1. Correspondingly greater differences in fertility are also shown, and when one considers the many uncontrolled factors contributing to infertility it is a noteworthy fact that the average infertility consistently declines with each increase of only one egg per week in the rate of production.

Number of Eggs per Clutch

The number of eggs per clutch, although an excellent measure of intensity, is more susceptible to error in an experiment of this type than is the number of eggs per week. If a hen lays four eggs per week and one is lost or broken, the week's eggs would be entered in the adjoining column. If, however, one egg is lost from a clutch of four, it may create two apparent clutches which are removed one to three groups from the correct one. Obviously, the larger the clutch the greater the chance of such error occurring, and the more serious the displacement when it does occur. Nevertheless, the large number of eggs considered in this study should make apparent any marked relationship that may exist between size of clutch and degree of infertility. In considering the results of this study it is important to remember that errors in the data will tend to minimize rather than to magnify the apparent degree of such a relationship.

Accordingly the incubated eggs of 1,178 hens were tabulated with respect to the size of the clutch in which they were laid, and the proportions of infertiles in clutches of different sizes were calculated. All complete clutches laid during February, March, and April were included, with the result that larger numbers of eggs and somewhat different levels of infertility are recorded in table 3 than in table 2. As with the two measures of intensity previously considered, the size

of clutch was also found to bear a distinct relationship to the proportion of the eggs laid which were infertile. The clutches which were small, indicating a low intensity of production, included a greater proportion of infertiles than larger clutches, the eggs of which were laid at a more rapid rate.

TABLE 3.—*The proportion of infertile eggs among those laid in clutches of one to three and of more than three, 1935–39*

Year	Hens	Eggs laid	Infertile eggs in clutches of—		Difference	P (χ^2)
			1 to 3 eggs	4 to 41 eggs		
	Number	*Number*	*Percent*	*Percent*		
1935	217	8,739	18.3	12.1	6.2	<0.001
1936	237	7,762	29.4	22.7	6.7	<.001
1937	245	7,914	13.3	10.6	2.7	<.001
1938	249	6,745	13.3	10.0	3.3	<.001
1939	230	9,192	12.1	10.6	1.5	<.05
Total	1,178	40,352				

The data for the different years are not sufficiently homogeneous to be combined for the calculation of statistical significance of differences between the eggs in clutches of different size. Accordingly, for each year the infertility of eggs laid in clutches of one to three (inclusive) was compared with the infertility of the remaining eggs (table 3). Although the number of eggs considered in each comparison is thus reduced to less than 10,000, these numbers were adequate to show that in each year 1.5 to 6.7 percent fewer of the total eggs were fertile in the small clutches than in the large. The proportion of infertile eggs was accordingly 14.6 to 29.6 percent greater in the small clutches than in clutches of four or more eggs. Although these differences are less striking than those presented in figure 1, they are nevertheless shown by the χ^2 test to be highly significant. With odds of more than 999:1 against the occurrence by chance of the differences found in 4 of the 5 years, it is obvious that eggs from small clutches tend to be less fertile than those from large clutches.

DISCUSSION

A study of infertility in the fowl is simplified, as compared with mammals, by the fact that a comparatively accurate distinction can be made between infertility and early embryonic mortality. That it is nevertheless difficult to ascribe to any particular cause a specific degree of infertility is shown by the diverse reports that age (*17*, *23*), temperature (*14*, *26*), breed (*16*), size (*29*), disease (*12*), absence of genital papilla in males (*9*), preferential mating (*28*, *30*), number of matings (*8*), selective fertilization (*1*, *7*, *10*), and the time elapsed after the last mating (*7*, *8*, *18*, *19*) may all influence the percentage of infertile eggs produced.

It is therefore desirable whenever possible to use more than one measure of a factor that is thought to influence degree of infertility. It has been pointed out that for each of the three measures of intensity used in this study the inherent errors of the data or the methods of analysis may modify the results. This is well illustrated by the

disagreement among previous reports. Chlebaroff (*5*) expressed the opinion that the more intense the laying activity, the larger is the proportion of fertilized eggs laid, and vice versa. No data were given to substantiate this statement. Nicolaides (*25*) reported that of 26 females laying an average of 17.7 eggs during an experimental period, the mean percentage of fertile eggs was 79.2 and 84.2, respectively, for those laying fewer or more eggs than the average.

It was reported by Montemayor (*24*) that there is no definite relation between production and fertility. His conclusion is based upon the incubation of 18,669 eggs during 280 hatches distributed through a 48-month period (1928–31). Eggs from three different breeds were incubated in 10 different incubators. Although he agrees with the observations of others that fertility is a matter of individuality, nevertheless he selected his eggs for incubation from the daily production of the flocks studied and calculated percentage production from the flock average. It is a well-recognized fact that fluctuations in flock production are frequently merely a reflection of the proportion of birds which are laying at a given time, and not necessarily any indication of the individual's rate of production. Such individual differences as existed could not be measured by this method of selecting eggs and therefore any relationship within the individual between rate of production and infertility could not be detected.

After the preceding analyses (tables 1–3) were completed, Funk (*11*) reported a study in which one of the three measures of intensity used here, size of clutch, was shown to be associated with degree of infertility. With methods much superior to those of Montemayor (*24*) he found that eggs from clutches of two to six eggs each included 5.2 to 12.6 percent fewer infertiles than those laid in clutches of one egg each.

The use in the present study of data obtained over a 5-year period from large numbers of both males and females has rendered inconsequential such errors as are attributable to differences in the environment and genotype of the birds. Inaccuracies arising from errors in trap-nesting, recording, and handling of the eggs are largely distributed by chance in such large populations as those studied. The danger of drawing false conclusions from results obtained by a method which is handicapped by error in sampling has been minimized by comparing the results obtained by three different methods of measuring intensity. It is therefore highly significant that with each of the three methods of analysis a markedly greater proportion of infertiles was found among those eggs which were produced during periods when the intensity of production was relatively low.

The conclusion seems justified therefore that insofar as this relationship is concerned those details of poultry management which tend to induce maximum intensity of production during the incubation season will also tend to induce maximum fertility.

STUDIES TO DETERMINE THE CAUSES OF INFERTILITY

The mere fact that fluctuations in the rate of egg production are associated with measurable differences in fertility does not explain the reasons for this relationship. Since the degree of infertility obviously cannot influence the rate of ovulation, it appears most logical that rate of ovulation directly affects the fertility of the eggs laid. In

searching for some basis for this relationship it was therefore suspected that the means by which intensity of production may affect fertility is most likely to be some function of the ovary which varies directly with rate of ovulation.

Two facts make it appear that different rates of ovulation are associated with the secretion of different amounts of hormone by the ovary. (1) It has been shown by Corner (*6*) that the probable site of secretion of estrogen is the theca interna of the Graafian follicle. Marlow and Richert (*21*) have shown that the follicular membranes of fowl contain more than four times as much estrogen per unit of weight as the whole ovary with ova less than 6 mm. in diameter. (2) The observations of Warren and Conrad (*31*) show that the ova of the good layer develop at the same rate as those of the slow layer, but that the rapid layer has at any one time more ova in the final stages of growth. Thus the hen which ovulates at a rapid rate has a larger area of follicular (estrogen-secreting) tissue present in the body than has the hen which ovulates less frequently. That the volume of theca interna is also greater in the hen with many large follicles than in the hen with few is obvious from the fact that in the follicle of a very young oöcyte there is no theca interna (*27*).

High levels of estrogenic hormone in the body might influence fertility in the fowl (1) by increasing the ability of the ova to be fertilized; (2) by prolonging the functional survival of sperm in the oviduct; or (3) by inducing greater sexual receptivity, or desire for copulation on the part of the female. All three of these possibilities were studied experimentally.

Susceptibility of the Ova to Fertilization

Susceptibility of the ova to fertilization is a characteristic which is not readily studied by direct methods. The incidence of scattered infertiles among the fertile eggs following a single insemination suggests that it may be more difficult to fertilize some ova than others. However, suitable methods of study might demonstrate that many such "infertiles" are actually fertile, the embryo having died at a very early stage of development.

With the data obtained for this study only one measure of the influence of estrogens upon the ability of ova to be fertilized is possible, and that is effective only if very rapid elimination of the hormone from the body occurs following secretion. According to the explanation given by Warren and Conrad (*31*), there should be a maximum number of large ova present in the ovary at the beginning of a clutch, and a minimum at the end of the clutch, or when the last ovulation of a clutch occurs. There might, therefore, be slightly less estrogen in the body when the last two ovulations in a clutch occur than at the time of the first two. With this in mind the fertility of the first two eggs was compared with the fertility of the last two eggs in clutches of four or more. Such an analysis shows a difference of less than 2 percent between the two groups for each of the 5 years studied (table 4). Since the differences do not consistently favor either group and are obviously of no significance, it is clear that the position of the egg in the clutch does not influence its capacity for fertilization.

TABLE 4.—*The proportion of infertile eggs among the first two and last two eggs in clutches of four or more, 1935–39*

Year	Pens	Hens	Clutches	Infertile eggs in	
				First 2 of clutch	Last 2 of clutch
	Number	*Number*	*Number*	*Percent*	*Percent*
1935	15	217	732	11.5	13.4
1936	17	237	797	23.0	23.2
1937	20	245	557	10.9	10.4
1938	18	249	580	10.0	9.7
1939	21	230	751	9.2	11.0
Average (unweighted)				12.9	13.5

FUNCTIONAL SURVIVAL OF SPERM IN THE OVIDUCT

It has been frequently demonstrated that the oviduct is conditioned for reproduction by estrogenic hormone secreted by the ovary. Ovariectomy prevents this conditioning process. When a laying hen ceases to ovulate, marked atrophy of the oviduct occurs, indicating a marked reduction in the secretion of estrogens in the absence of large ovarian follicles. The oviduct again hypertrophies at the onset of ovulation or following the injection of synthetic estrogen. Such conditioning may conserve the energy and prolong the life of the sperm held in the oviduct, thereby prolonging the period of fertility following an insemination.

To test this hypothesis two experiments were made. First, two similar groups of hens were artifically inseminated by the method of Burrows and Quinn (*4*) and the duration of fertility determined. Each female was inseminated with 0.1 cc. of the mixed semen obtained from several males. This was twice the amount reported by Burrows and Quinn (*3*) as giving normal fertility, but it was used in this experiment to avoid fluctuations such as might be expected from marginal dosage. The hens of one group were given supplementary estrogen [3] to ascertain its influence upon sperm survival. Since the hormone might be expected to increase the fertility of hens that lay at a slow rate to the approximate level of fertility of hens that lay at a rapid rate, only those hens are compared in table 5 which laid at a rate of less than 55 percent (of the assumed maximum of one egg daily) or more than 70 percent. These levels of selection were used because they most nearly divide the populations of the larger groups into thirds. The fact that noninjected controls showed slightly longer duration of fertility (table 5, battery 2) than those receiving the supplementary hormone suggests that estrogen does not prolong the life of sperm in the oviduct.

Because of the small number of hens which laid at a slow rate, a second study (also reported in table 5) was made by comparing the duration of fertility of those hens which lay at a relatively slow rate, and therefore presumably secrete less hormone, with hens which ovulate at a rapid rate. Hens in pen F–61 (not in cages) were employed for two tests. It is of interest to note that each of the four groups (table 5) which laid at a rate of less then 55 percent laid fertile

[3] The hormone used was Progynon-B (estradiol benzoate) kindly furnished by Dr. Max Gilbert, of the Schering Corporation, Bloomfield, N. J.

eggs for a shorter average time than the groups of hens which laid at a rapid rate. Because part of the hens kept in cages were injected with hormone and also because the group as a whole included relatively few hens which ovulated at a slow rate, they should not be used in a statistical test for the significance of correlation between the rate of ovulation and the percentage of eggs laid which were infertile. This reduces the number of individuals available, but for the 52-hen tests remaining (table 5, F–61) there exists a correlation coefficient of 0.29 ± 0.13 between rate of egg production and duration of fertility in days. Inasmuch as there is a probability of less than 5 percent that such a relation may have resulted by chance, it may be concluded that sperm tend to survive somewhat longer in the oviducts of rapid than of slow layers.

TABLE 5.—*Duration of fertility following artificial insemination of hens that laid at a slow or at a rapid rate, as affected by supplementary estrogen*

Group or pen	Hens	Production [1]	Hens with production > 55 percent		Hens with production < 70 percent	
			Number	Duration of fertility	Number	Duration of fertility
	Number	*Percent*		*Days*		*Days*
Battery 1 injected [2]	16	65.4	2	8.5	10	10.7
Battery 2, controls	23	66.6	5	8.8	13	12.2
F–61, first test	29	63.6	10	10.5	12	14.3
F–61, second test	23	58.8	6	9.7	7	10.3
Average (unweighted)				9.4		11.9

[1] $\frac{\text{Number of eggs} \times 100}{\text{Number of days} \times \text{hens}}$

[2] Injected with 100 rate units Progynon-B daily beginning 2 days before insemination.

INDUCTION OF SEXUAL RECEPTIVITY

Observations in this laboratory and the published results of others show that in some hens fertility declines rapidly following insemination. With such individuals, relatively frequent mating is obviously necessary if the highest possible proportion of the eggs laid are to be fertile. That a high degree of infertility may be due to a lack of sexual receptivity on the part of the female is indicated by the following experiment.

During the 1939 incubation season there were 11 hens in the breeding pens at Cornell University which were laying few, if any, fertile eggs. These hens were therefore inseminated artificially with semen from the respective males with which they had been mated. The proportions of fertile eggs among those laid during the 10 days previous to artificial insemination, and from the second to the eleventh day after the first artificial insemination, were as follows:

Before artificial insemination 80 eggs, 2.5 percent of which were fertile.

After artificial insemination 138 eggs, 60.9 percent of which were fertile.

The fact that the hens in this experiment laid fertile eggs following insemination strongly suggests that the previous infertility was a result of failure to copulate. These data do not show that the female

was wholly responsible, but since it has previously been shown that matings are largely controlled by the female (*22*, *28*), it is apparent that desire for copulation on the part of the female has a marked influence upon the fertility of the eggs laid.

It is generally believed that nonlaying hens mate infrequently, if at all. This, in addition to the above results, suggests two questions concerning the method by which frequency of ovulation can influence infertility. (1) Are hens which lay most rapidly more fertile because they copulate most frequently; (2) Can the frequency of copulation be increased in the laying and nonlaying hen by injections of synthetic estrogen?

Data have been obtained by two authors which furnish a specific answer to the first of these questions. By rearranging the data of Wilkins [4] and Heuser [5] the summary in table 6 was obtained to show the average number of copulations made by hens which do not ovulate, or which ovulate at a moderate or a rapid rate.

Expressed in a different way, Heuser found a coefficient of correlation of 0.609 ± 0.109 between the number of matings and the rate of egg production. These observations make it very clear that those hens which ovulate most rapidly also copulate most frequently.

TABLE 6.—*Rearrangement of data from Wilkins and from Heuser (see text) to compare number of eggs laid with the average number of copulations made by hens that ovulated rapidly, moderately rapidly, or not at all.*

Investigator and length of experimental period	Hens	Eggs laid (average)	Copulations (average)
	Number	*Number*	*Number*
Wilkins, 18 days	11	0.0	4.1
	16	6.2	13.3
	13	13.6	22.8
Heuser, 13 days	4	.0	2.0
	15	4.2	14.9
	17	9.4	21.8

To study the second question, concerning the influence of synthetic estrogen upon receptivity of the female, an experimental pen was assembled which included three immature pullets 15 weeks of age, three nearly mature but nonlaying pullets, four pullets which had recently started to lay, four yearling hens which were laying at a rapid rate, and three hens from a strain bred for low fecundity (*13*) which were genetically incapable of ovulating during September under normal conditions.

Males were placed with these birds during observation periods of 4 to 5 hours per day and the mating reactions recorded on September 17, 19, 20, 21, 22, 25, 27, 29, 30, and October 1. Following observations on September 20, and daily thereafter for 11 days, some of the females were injected (intramuscularly) with 100 to 1,000 rat units of Progynon-B (estradiol benzoate).

The daily dosage of 1,000 rat units of estrogen was considered quite large for a hen, since the injection of 900 to 1,500 rat units during 30 hours will regularly induce oestrus in the ewe (*20*). However, with

[4] WILKINS, R. H. SOME FACTORS INFLUENCING THE FERTILITY AND HATCHING POWER OF EGGS OF THE DOMESTIC FOWL. (Thesis, Cornell Univ.) 1915.

[5] HEUSER, G. F. A STUDY OF THE MATING BEHAVIOR OF THE DOMESTIC FOWL. (Thesis, Cornell Univ.) 1916.

one exception there appeared to be no relationship between the amount of hormone injected and frequency of copulation among the laying hens. The 15-week-old pullets showed no desire to copulate at any time and the largest number of copulations made in the 11-day period by any of the nonlaying yearling hens was only three.

It is not probable that this apparent inability of estrogen to induce copulation was a result of insufficient dosage. In those hens which were not laying there was a marked hypertrophy of the oviduct following injections of the hormone (fig. 2). Although the resting oviduct attained a weight during this 12-day experiment of only about one-half that of the oviduct in a laying hen, certainly such marked stimulation given to hens already moderately stimulated by an active ovary should affect frequency of copulation if estrogens were the primary cause of sexual receptivity.

Discussion

The fact that no significant difference in fertility was found between the first two and last two eggs in a clutch (table 4) substantiates the recent conclusion by Funk (*11*) that "The position of the egg within a given clutch apparently is not related to fertility."

The consistently longer duration of fertility in the hens which ovulated most rapidly (table 5) and the significant coefficient of correlation between rates of ovulation and duration of fertility in the hens of F–61 show that spermatozoa probably survive longer, on the average, in those hens which ovulate rapidly than in those which lay at a slow rate. In a similar experiment reported by Warren and Kilpatrick (*32*) hens which laid at a rate of 60 percent or more had an average duration of fertility 1.64 days longer than that of hens laying at a rate of less than 60 percent, but this difference was not considered significant.

The idea may be inferred from much of the literature concerning sexual behavior in the fowl that because copulation occurs so frequently and the average duration of fertility may be more than 1 week, the frequency of copulation is not a limiting factor in the practical attainment of maximum fertility. That it is actually of considerable importance is shown, however, by the improved fertility obtained in the writer's experiments following artificial insemination of hens which were quite infertile when mated naturally with the same males. The value of frequent matings was also shown by Curtis (*8*), who found that although more than one mating did not lengthen the duration of fertility, it did increase the proportion of the eggs laid which were fertile from 72.6 to 83.3 percent. The additional fact that the spermatozoa of a new male quickly supplant those of a preceding male (*7*, *32*), is indirect evidence that sperm, though long-lived, retain maximum efficiency for a relatively short time.

One limiting factor affecting the average fertility in a flock is, not the average frequency of copulation by all birds, but rather the minimum number of copulations by the few birds that pull down the flock average. The observations of Wilkins [6] show that it is not uncommon for some laying hens to mate only once in two or more days. Since some natural matings are infertile (*22*, *25*) the actual time between effective matings is longer than observations indicate.

[6] See footnote 4.

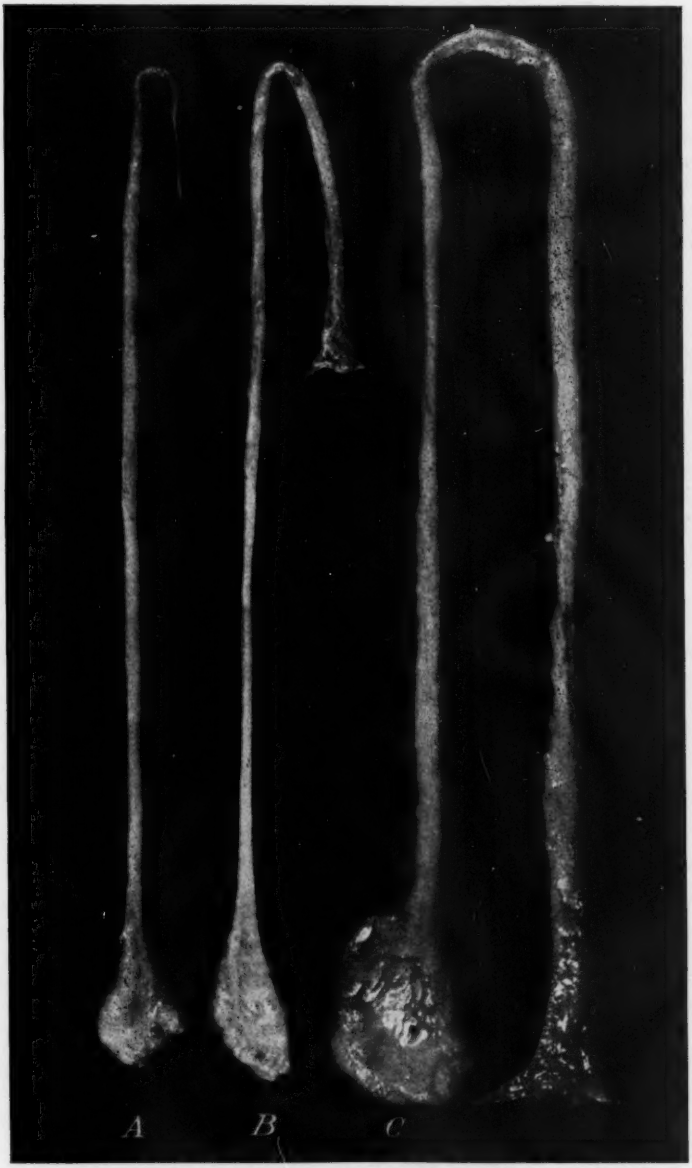

FIGURE 2.—The oviducts (without vagina) of three nonlaying White Leghorn yearling hens: *A*, Control, weight 3.6 gm., length 25.5 cm.; *B*, injected with 500 rat units of Progynon-B daily for 12 days, weight 4.4 gm., length 31.5 cm.; *C*, injected with 1,000 rat units of Progynon-B daily for 12 days, weight 20.2 gm., length 53.0 cm.

Another limitation upon fertility of the flock results from the inability of some females to maintain fertility more than 2 or 3 days after a single mating. Curtis (*8*) found the duration of fertility following copulation to be as short a time as 2 days. Kaupp (*18*) reported a decline of fertility after 3 days following removal of the male. Bonnier and Trulsson (*2*) found that on the second day after artificial insemination a larger proportion of fertile eggs was obtained than on subsequent days. Similar results were obtained with two groups of hens in this study (F–61, table 5). The hens of one group were artificially inseminated once and gave higher fertility (100 percent) on the second day following than they gave later. Hens of the other group were inseminated on each of 2 consecutive days. Eggs laid the third day after the first insemination were lost, but the records for other days show that fertility declined after reaching a maximum of 94.7 percent on the second day.

Among the hens which copulate frequently the duration of fertility following mating can have relatively little influence upon the proportion of the eggs laid which are infertile. The results of this study indicate that the principal reason for the high level of infertility among eggs which are produced at a slow rate is the tendency for hens to copulate infrequently during periods of infrequent ovulation. Just how sexual receptivity is controlled by the rate of ovulation, or by those factors which influence rate of ovulation, remains to be determined.

SUMMARY

An analysis of the incubation records of more than 1,200 hens was made to determine the relationship between the proportion of eggs laid which are infertile and the rate of egg production.

The hens which laid 13 to 22 eggs during a 6-week period produced a larger proportion of infertile eggs during that time than birds which laid at a more rapid rate.

The eggs laid during weeks when one to seven eggs were laid showed, respectively, a degree of infertility which was inversely proportional to the number of eggs laid per week.

The proportion of infertile eggs was significantly higher among those which were laid in clutches of one to three eggs than in those laid in clutches of more than three.

During periods when the rate of ovulation is low, hens copulate less frequently and probably have a shorter duration of fertility following insemination. These two factors, particularly the first, are believed to be responsible for the high level of infertility among eggs laid during periods when the intensity of production is low.

The duration of fertility following artificial insemination was not prolonged by daily injections of 100 rat units of Progynon–B per bird.

Sexual receptivity in the fowl was influenced only slightly, if at all, by 12 daily injections of 100 to 1,000 rat units of Progynon–B.

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THE CYSTINE CONTENT OF ELEVEN VARIETIES OF SOYBEANS[1]

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INTRODUCTION

The soybean (*Soja max* (L.) Piper) is fast becoming a factor of major importance in American agriculture. A valuable crop to the agronomist, a source of raw materials for many industrial commodities, such as glue, plastics, paint, artificial wood, etc., as well as a valuable feed and food supplement for both man and animal, the soybean occupies an important place among the cultivated crops in many parts of the world. While soybean hay, whole soybeans, and soybean oil are valuable foodstuffs, the proteins of the beans are of chief interest and importance so far as the nutritive value of the crop is concerned.

By 1925, 1,133 varieties had been described, and of these more than 100 named varieties are widely grown or are being distributed in the United States (*16*).[2] Some varieties are useful for their oil content or for their feeding value for animals. However, a number of the newer varieties are valuable as food for human beings. Woodruff (*28*) of the University of Illinois has tested 467 varieties of edible soybeans for their eating qualities and has rated 6 as very good and 70 as good.

The value of soybeans or soybean oil meal, or of any feed, as a source of protein to the animal body depends not only upon the total amount of protein present, but also upon its digestibilty and biological value when consumed. That the total amount of protein in a sample of soybeans may vary widely, depending upon the variety, soil fertility, climatic conditions, etc., has been shown by a number of investigations. References to investigations of this nature to 1938 may be found in a review by the Soybean Nutritional Research Council (*10*).

Osborne and Campbell (*19*) isolated several types of proteins from soybeans and gave to the principal one, a globulin, the name glycinin. This protein amounted to 16.6 percent of the meal or between 80 and 90 percent of the total protein present. They also obtained evidence of the existence of another globulin which was even more soluble than glycinin. In addition to these two globulins there were isolated a legumelin, amounting to about 1.5 percent of the seed, and a small amount of proteose.

A number of investigations (*9, 12, 14, 15*) have indicated that the proteins of raw (usually defatted) soybeans have a low nutritive value. Mitchell and Smuts (*15*) and, later, Shrewsbury and Bratzler (*22*), Hayward, Steenbock, and Bohstedt (*8*), and Smuts and Marais (*23*) have shown that the amino acid limiting the utilization of the absorbed nitrogen from soybeans was cystine.

[1] Received for publication April 15, 1940.

[2] Italic numbers in parentheses refer to Literature Cited, p. 212.

In view of these findings and the wide variations in the protein content of different varieties of soybeans, it is of interest to examine, in more detail, the chemical nature and, in particular, the cystine content of different varieties of soybeans. Unfortunately there has been but little work done on the methionine content of these beans.

Osborne and Clapp (*20*) analyzed glycinin and found the amino acid content to be similar to that of casein. They reported, however, no cystine values for the isolated protein. Csonka and Jones (*4*) also analyzed the glycinin from the seeds of several varieties of soybeans for cystine, tryptophane, and tyrosine. These workers reported a variation in the cystine content between 0.74 percent for the Illini variety and 1.45 percent for the Manchu variety. Csonka, Murphy, and Jones (*3*) presented evidence which indicated that glycinin, as ordinarily prepared, was not an individual protein and Csonka and Jones explained the wide variation in the cystine content of their different glycinin preparations on the basis of variations in the relative proportions in which the different globulins comprising the glycinin fractions were present in the different varieties of soybeans.

Later (*5*), Csonka and Jones, after failing to obtain satisfactory cystine determinations on defatted soybean meal, determined the cystine content of 10-percent sodium chloride extracts (containing 85 to 90 percent of the total nitrogen of the meal) of six varieties of soybeans. At the same time tryptophane and tyrosine were determined directly on the defatted meals of the same varieties. Using a modification (*2*) of the Sullivan (*24*) method, they found variations in the cystine content of the defatted meals of from 0.287 percent for the Illini variety to 0.491 percent for a Herman variety.

Sasaki (*21*) analyzed soybean protein for several amino acids but reported no values for either of the sulfur-containing amino acids. Mashino and Nishimura (*13*) studied the nitrogen distribution, by the Van Slyke method, in the defatted beans from two varieties, Tsurunoko-daizu and Machurian, the latter of which was analyzed in the unheated and heated states after the oil had been removed either with solvent or by pressure. They found but little variation in the nitrogen distribution of their samples and reported an average of 1.74 percent of cystine nitrogen. Earlier, and also using the Van Slyke method, Hamilton, Uyei, Baker, and Grindley (*7*) reported an average value of 1.46 percent in Medium Early Yellow soybeans, and Nollau (*17*) reported 1.52 percent, both values being cystine nitrogen expressed as a percent of the total nitrogen.

Baernstein (*1*) found, in his study of a number of proteins, that soybean glycinin contained 1.84 percent methionine. The methionine sulfur amounted to 47.2 percent of the total sulfur. However, Tomiyama and Hanada (*25*) were able to isolate but 0.08 percent of methionine from dry, ash-free soybean protein.

The study to be reported here is concerned with the cystine content of 11 varieties of soybeans, all grown in the same year (1933) on a small plot of ground, the soil of which was very uniform. The beans were taken from groups of plants systematically replicated 10 times over the entire plot.[3]

[3] These samples were furnished by Prof. C. M. Woodworth of the Department of Agronomy.

PROCEDURE

Each of the 11 varieties of soybeans used was clean and well cured when received. The beans were first ground, avoiding the generation of heat, so as to pass through a 40-mesh sieve. In a few cases the beans were ground even finer. The method of preparation of a fat-free, carbohydrate-free protein sample was similar to that used by Hamilton, Nevens, and Grindley (*6*), with only slight modifications. In this procedure triplicate 15-gm. samples of the finely ground, dry beans were thoroughly extracted, first with absolute ethyl ether, then with absolute ethyl alcohol. These extracts were discarded after they were found to be practically free of nitrogen.

The residues from the ether and alcohol extractions were then extracted with dilute sodium hydroxide solutions. Eight to ten extractions, using 400 cc. of 0.1-percent Sodium hydroxide for each extraction, were first made. Then extractions were made in which 200 cc. of 1-percent sodium hydroxide was used for each extraction. These extractions were continued until the extract no longer gave a test for protein, usually 6 to 8 extractions being necessary. Centrifuging and decanting were used to separate extract from residue. Each extract was immediately neutralized with acetic acid after being decanted.

The combined extracts from each sample were then carefully concentrated to about 200 cc. An equal volume of concentrated hydrochloric acid was added and the protein hydrolyzed by gentle boiling under a reflux condenser for about 20 hours. The hydrolyzate was then cautiously concentrated in a beaker to about 125 to 150 cc. and neutralized with 40-percent potassium hydroxide solution. After the solution was made barely acid to litmus, 2 to 3 gm. of norit were added, and the mixture boiled gently for a few minutes. The norit was filtered off and washed with hot water. After the filtrate had stood overnight, it was again treated with a small amount of norit. The solution thus obtained was clear and slightly yellowish, but this color did not seem to interfere with the colorimetric estimation of cystine.

Cystine was determined in the extracts by Lugg's (*11*) modification of the Sullivan (*24*) method.

RESULTS

The results of this study are presented in the accompanying tables. Table 1 gives the usual chemical analyses and table 2 gives the results of the cystine determinations on the 11 varieties of soybeans. The routine chemical examination shows a considerable varietal variation between the samples, this being particularly true of the protein content. The percentage of protein (total nitrogen $\times$ 6.25) varied from 35.88 (Peking) to 43.69 (Manchu), averaging 39.11 for the 11 varieties. The ether extract varied from 16.07 (Ito San) to 19.16 (Mansoy), averaging 17.86 percent for all varieties. Since these varieties had about the same moisture content and since all were grown in the same year on uniform soil in a small plot of ground, the differences observed strongly indicate varietal differences of considerable magnitude.

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TABLE 1.—*Percentage composition of 11 varieties of soybeans grown in Illinois and harvested in 1933*

Variety	Moisture	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Ash	Total nitrogen
Illini	7.06	37.75	18.82	4.37	27.28	4.72	6.04
Ohio 13-177	7.04	38.31	18.75	4.54	26.32	5.04	6.13
Harbinsoy	7.12	39.69	18.45	4.24	25.50	5.00	6.35
Virginia	6.89	38.81	17.90	4.65	26.71	5.04	6.21
Mansoy	7.17	36.25	19.16	4.41	27.84	5.17	5.80
Ito San	6.68	41.44	16.07	3.97	26.74	5.10	6.63
Dunfield	6.73	36.38	17.62	4.12	30.45	4.70	5.82
Manchu	7.34	43.69	17.80	3.69	22.44	5.04	6.99
Peking	7.20	35.88	17.38	5.03	29.41	5.10	5.74
Mandarin	7.82	41.44	16.66	4.12	24.92	5.04	6.63
Morse	7.41	40.56	17.91	3.97	25.02	5.13	6.49
Average	7.13	39.11	17.86	4.28	26.61	5.01	6.26

TABLE 2.—*Cystine content of 11 varieties of soybeans*

Variety	Total nitrogen extracted	Cystine content		
		In whole soybeans [1]	Cystine nitrogen as percentof total nitrogen	Cystine per gram of nitrogen
	Percent	*Percent*	*Percent*	*Milligrams*
Illini	96.6	0.366	0.696	59.7
Ohio 13-177	99.1	.266	.433	42.3
Harbinsoy [2]	92.8	.256	.464	39.8
Virginia	96.5	.213	.385	33.1
Mansoy	95.5	.553	1.042	89.4
Ito San	90.8	.413	.703	60.3
Dunfield	97.9	.439	.858	73.7
Manchu	99.4	.451	.742	63.7
Peking	95.6	.276	.564	48.4
Mandarin [2]	94.4	.507	.848	72.8
Morse	99.2	.346	.617	53.0
Average	96.2	.371	.668	57.8

[1] The coefficients of variability for duplicate or more determinations on the same variety (the number of separate determinations made on the same variety are indicated by the numbers in parentheses) were as follows: Illini (3) 2.5 percent, Ohio (3) 2.6, Harbinsoy (5) 6.2, Virginia (2) 3.7, Mansoy (3) 0.9, Ito San (3) 3.4 Dunfield (3) 5.7, Manchu (3) 2.7, Peking (3) 5.4, Mandarin (2) 5.1, and Morse (2) 0.86.

[2] The extraction procedure in this case was modified by using a 2-percent trichloraceitic acid extraction after the alcohol extraction and then precipitating the protein extracted with colloidal iron.

It may be noted from table 2 that the cystine determinations were made on extracts which contained on an average 96.2 percent of the total nitrogen in the whole beans. In only 2 of the 11 samples was there less than 93 percent of the total nitrogen in the extract.

Regardless of the manner in which the cystine is expressed, i. e., as a percent of the whole seed, as cystine nitrogen in percent of the total nitrogen, or as milligrams of cystine per gram of total nitrogen, there are large and significant differences. The percentage of cystine in the whole seed varied from 0.213 (Virginia) to 0.553 (Mansoy). The percentage of the total nitrogen which was cystine nitrogen varied from 0.385 (Virginia) to 1.042 (Mansoy), that of Mansoy being nearly 200 percent greater than that of Virginia. Expressed as milligrams of cystine per gram of total nitrogen, the variation was 33.1 (Virginia) to 89.4 (Mansoy).

Because of the completeness with which the total nitrogen of the beans was extracted, the cystine values reported here should repre-

sent more accurately than any heretofore published the actual amount of this amino acid present in the whole bean. The only previously reported results with which the results of this investigation may be compared, are those reported by Csonka and Jones (*5*), and even here the samples were not exactly comparable since Csonka and Jones analyzed a 10-percent sodium chloride extract (containing 85 to 90 percent of the total nitrogen) of the defatted meals. And of course difference in soils and environment might also add to any differences observed. Nevertheless, there were two varieties studied by both laboratories. Csonka and Jones reported 0.287 percent of cystine in defatted meal from Illini beans, while 0.451 percent of cystine may be calculated to have been present in the fat-free beans analyzed by the writers. Similarly, Csonka and Jones found 0.388 percent and the writers found 0.334 percent of cystine in the fat-free Peking variety. That there is probably a higher content of cystine in the glycinin fraction than there is in the entire mixed proteins of the soybean, is indicated by Csonka and Jones (*4*), who reported 0.74 and 1.45 percent cystine in the glycinin from the Illini and Manchu varieties, respectively, while the writers found but 0.366 and 0.451 percent of cystine in the whole beans of the same varieties.

While the results of the present study, as well as those of previous investigations, strongly indicate considerable varietal differences with respect to the cystine content of soybeans, the effects of other factors should not be overlooked. The same varieties grown in a single location may also vary considerably from year to year. O'Kelly and Gieger (*18*) found, over a 7-year period, variations in the protein content between 35.55 and 40.67 percent for the Loredo beans and between 39.91 and 44.64 percent for the Mammoth Yellow variety. That other environmental conditions, such as rainfall, fertility of soil, and temperature, may cause large differences in the protein content of the same variety has been shown by Webster and Kiltz (*26*). These investigators reported the protein content of four varieties of soybeans grown in two different counties of Oklahoma. Considerable variation was found in all varieties, but by far the greatest was that exhibited by the Loredo beans that contained 35.00 percent of protein when grown in Craig County and 47.50 percent when grown in Payne County (at Stillwater).

Thus, while wide differences observed in this study in the cystine content of different varieties of soybeans probably represent true varietal differences, the above-mentioned studies, indicating that environmental factors may cause wide differences in the protein content of the same variety, suggest the probability that the small differences observed in the cystine content of different varieties may not be true varietal differences.

Since the mixed proteins, rather than isolated proteins, are used most often as human and animal foods, these values on the cystine content of several common varieties of soybeans should be of interest. Also since cystine has been shown to be the limiting amino acid in the utilization of certain soybeans, a knowledge of the varietal variation should be of value to all interested in using soybeans as a protein supplement. It is conceivable, on the basis of their cystine content, that certain varieties would find their greatest value for feeding purposes while other varieties may be grown for industrial

purposes. For those varieties in which cystine has been shown to be the limiting factor in the utilization of their protein, it is obvious (*27*) that methionine also must be present in insufficient amounts to satisfy the combined requirements for both sulfur-containing amino acids.

Although Baernstein (*1*) reported the presence of 1.84 percent of methionine in glycinin from soybeans, little is known concerning the variation of this amino acid in different varieties of whole soybeans. It is, however, reasonable to suppose that there exists among different varieties a variation of considerable magnitude in the methionine content.

The inadequacy of a chemical estimation of a food nutrient in satisfying the animal's requirements may be emphasized in this connection. Compared with other foods and feeds, soybeans in general are not particularly low in their content of sulfur-containing amino acids, as indicated by chemical analyses. Nevertheless the sulfur-containing amino acids limit the utilization of raw soybean protein in growing animals. Heating the soybeans apparently makes the cystine or its equivalent methionine more available so that the nutritive value of the heated protein is approximately equal to that of the raw protein supplemented with cystine (*8*).

SUMMARY AND CONCLUSIONS

The cystine content of extracts, containing on an average 96.2 percent of the total nitrogen content of 11 varieties of soybeans all grown in the same year on uniform soil, was determined. Expressed as a percent of the whole soybean seed, the cystine content varied from 0.213 for Virginia beans to 0.553 for Mansoy beans. Expressed in milligrams of cystine per gram of nitrogen, a variation from 33.1 for the Virginia beans to 89.4 for the Mansoy variety was found. These latter figures show nearly 200 percent variation, much of which probably represents true varietal differences.

Since cystine or its equivalent in nutrition has been shown to be the limiting factor in the utilization of at least certain varieties of soybeans, and since there may be large differences in their cystine content, it is concluded that perhaps certain varieties should find their greatest value as protein supplements in human diets and in animal rations while others should find their greatest usefulness in the industries.

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SOIL-FERTILITY STANDARDS FOR GROWING NORTHERN HARDWOODS IN FOREST NURSERIES [1]

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INTRODUCTION

This paper is supplemental to a previous report dealing with soil-fertility standards for growing northern conifers in forest nurseries (*9*).[3] The general principles and technique therein outlined were followed in the present study. The fertility standards for growing northern hardwoods in forest nurseries were arrived at by analysis of soils from normally developed productive stands that included the following species: Yellow birch (*Betula lutea* Michx. f.), hard maple (*Acer saccharum* Marsh.), basswood (*Tilia americana* L.), American elm (*Ulmus americana* L.), and white ash (*Fraxinus americana* L.).

No attempt was made in the present study to establish fertility standards for the heavy-seeded species, such as oak, hickory, and walnut. During their first growing season such trees feed to a large extent on nutrients of the seed, and are less dependent upon the soil-fertility level.

DESCRIPTION OF AREAS SAMPLED

As a general rule, northern hardwoods occur in nature as associates of various forest types, namely, hemlock, yellow birch, maple; maple, basswood, elm; oak, maple, ash; oak, ash, hickory, and so forth. Depending on circumstances, the soil sampling was applied to the entire forest type or to local groups of the species studied.

The total number of sampled areas was limited to 200. However, great care was exercised in the selection of localities; stands affected by logging, pasturing, or fire, as well as those younger than 100 years, were rejected. Nearly 60 percent of all samples were collected from the mixed stands of hard maple, basswood, and elm. Most of these stands could be classified as true virgin forest. The soil samples for yellow birch standards, constituting approximately 25 percent of the total number, were taken largely from groups of this species interspersed in stands of hemlock. Difficulties were experienced in locating undisturbed growth of white ash, and most of the samples were secured from comparatively well preserved wood lots or park areas containing a considerable percentage of this species.

The sampling was rather uniformly distributed throughout the following region: Northeastern Minnesota, including the Chippewa National Forest, as far as the southern boundary of Superior National Forest; the entire area of noncalcareous drift of Wisconsin, including

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[3] Italic numbers in parentheses refer to Literature Cited, p. 221.

Chequamegon and Nicolet National Forests; and the northeastern portion of upper Michigan, particularly the Ottawa National Forest. A few areas were included from southeastern Minnesota, northeastern Iowa, southern Wisconsin, northern Illinois, and western Indiana.

The soils analyzed were for the most part of a loam or silt loam texture having approximately 40 percent of silt (0.05–0.005 mm.) and 25 percent of clay (less than 0.005 mm.) particles. The soils supporting yellow birch, as a rule, belonged to the true Podzol type with a more or less developed layer of raw humus. The rest of the hardwoods studied were located on moderately or slightly leached soils with incorporated humus of a mull nature.

CONTENT OF NUTRIENTS AND ASSOCIATED CONDITIONS IN SOILS SUPPORTING DIFFERENT HARDWOOD SPECIES

The results of analyses of soils supporting different hardwood species for pH value (*5*), base-exchange capacity (*2*), total nitrogen (*1*), available nitrogen (*3*, *4*), available phosphorus (*6*), available potassium (*8*), replaceable calcium, and replaceable magnesium (*2*) are reported in table 1.

TABLE 1.—*Reaction, base-exchange capacity, total nitrogen, and available nutrients in soils supporting different hardwood species* [1]

Species	Reaction (pH)	Base-exchange capacity per 100 gm.	Total N	Approximate level of available N	Available P_2O_5 per acre	Available K_2O per acre	Replaceable per 100 gm. Ca	Replaceable per 100 gm. Mg
		Milli-equivalent	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Milli-equivalent*	*Milli-equivalent*
Yellow birch	5.31±.07	11.67±.6	0.165±.010	32	63.3± 8.5	167.1±10.9	5.2±.4	1.6±.2
Hard maple	5.79±.12	13.76±.9	.185±.012	41	136.7±12.4	242.3±17.5	8.3±.9	2.1±.3
Basswood	5.83±.09	14.54±.6	.197±.009	47	159.8±11.4	273.3±15.0	9.1±.7	2.5±.2
American elm	5.88±.11	15.02±.8	.211±.007	45	174.5±12.9	274.7±17.4	9.8±.7	2.3±.1
White ash	6.23±.07	15.83±.9	.217±.012	54	185.3±14.2	293.8±21.4	11.2±.8	2.9±.3

[1] Standard errors given.

The mean values and standard errors presented in table 1 express the fertility of the upper 8-inch layer of the soil profile. These figures were obtained by an analysis of soil samples collected from the separate soil horizons, such as litter, duff, humic layer, and leached layer. The thickness of each horizon, its volume weight, and its content of nutrients were considered in computing the average fertility of each 8-inch layer.

The amounts of available nitrogen, i. e., ammonia and nitrates combined, vary greatly with the season and weather conditions. Because of this, medians instead of arthmetic means are reported for the content of these constituents. Soils under yellow birch contained soluble nitrogen predominantly in the form of ammonia. Soils under white ash had about 90 percent of their available nitrogen in the form of nitrates. The rest of the hardwood soils showed but a slight excess of nitrates over ammonia, on the average.

The analyses show that the nitrogen-phosphoric acid-potash ratio for yellow birch approaches 1–2–5, thus being the same as that

found for coniferous species. The ratio for the other hardwoods lies in the proximity of 1–3–5.

TABLE 2.—*Standards of fertility for nursery blocks raising different species of trees*

Species	Reaction (pH)	Base-exchange capacity per 100 gm.	Total N	Available P_2O_5 per acre	Available K_2O per acre	Replaceable Ca per acre	Replaceable Mg per acre
		Milli-equivalent	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Yellow birch	5.3	12.0	0.16	60	175	2,000	300
Hard maple, Basswood, American elm	5.8	14.0	.20	150	275	3,500	500
White ash	6.2	16.0	.22	185	300	4,500	700

Table 2 presents in round numbers the desirable levels of different soil factors which may serve as standards in the maintenance of nursery soil fertility. From a practical standpoint the soil-fertility levels for hard maple, basswood, and elm do not differ significantly. Therefore, average values given for these three species in table 2 seem to be well justified, especially if one considers the resulting simplification in nursery soil management.

In this study no attempt was made to correlate the analytical data with the results of greenhouse investigations. However, in order to provide a simple illustration of the workability of the standards proposed, a number of soils depleted in nutrients were placed in ½-gallon glazed jars, the fertility adjusted to the desired levels by the application of peat and mineral fertilizers, and the jars seeded to various hardwood species. Figure 1 shows the results achieved with American elm and white ash on a Miami loam soil which had been under cultivation for 70 years.

ADJUSTMENT OF SOIL CONDITIONS

The general directions for adjustment of fertility in nursery soils have been previously outlined (*9*). In growing hardwoods, however, special consideration must be given to the problem of nitrogen fertilization.

The majority of climax hardwood species are heavy nitrogen feeders. With a relatively high pH value of the soil, the activity of micro-organisms in hardwood beds is intensive. As a result, most of the available nitrogen occurs in the form of nitrate, i. e., an acid radical which cannot be held in soil by the base-exchange fraction. Nursery beds are subject to strong leaching because they are exposed both to natural precipitation and artificial irrigation. A combination of these factors may necessitate the addition of soluble nitrogen salts, such as ammonium sulfate, sodium nitrate, or ammonium nitrate, even on soils with adjusted fertility. These are usually applied as liquid fertilizer after nitrogen deficiency is manifested by discoloration of seedlings.

Table 3 gives the range of annual applications of elemental nitrogen likely to be required by different hardwood species. Under unfavor-

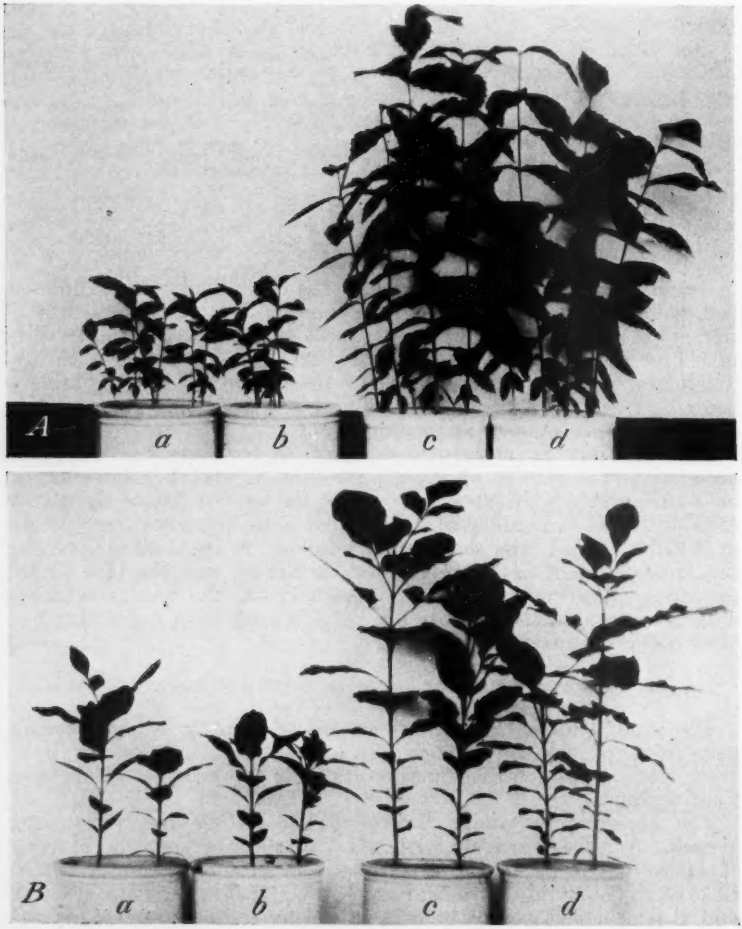

FIGURE 1.—Growth of hardwood seedlings on a depleted (*a*, *b*) Miami loam soil from the University of Wisconsin arboretum and on the same soil with the fertility adjusted (*c*, *d*) to the recommended standards: *A*, 4-month-old American elm; *B*, 5-month-old white ash.

able conditions, as, for example, in rainy summers or in seasons when warm periods alternate with heavy rains, nearly double the maximum amounts indicated in table 3 may be necessary to prevent nitrogen starvation of the stock.

TABLE 3.—*Approximate range of annual applications of elemental nitrogen or of nitrogen salts likely to be required by different tree species*

Form of nitrogen	Requirement per acre for—		
	Yellow birch	Hard maple, basswood, American elm	White ash
	Pounds	*Pounds*	*Pounds*
Elemental	20–40	30–50	40–60
20-percent ammonium sulfate	100–200	150–250	200–300
16-percent sodium nitrate	----------	175–300	250–375

Yellow birch, as a rule, presents no problem in the selection of the kind of nitrogen fertilizer. In nature it feeds, by and large, on ammoniacal nitrogen, and it responds readily to ammonium sulfate. The rest of the hardwood species, especially white ash, under natural conditions feed wholly or partly on nitrates and should receive at least a portion of the nitrogen fertilizer in this form. The application of all nitrogen fertilizer as nitrate would seldom be advisable because of the instability of this compound in the soil. In many instances ammonium nitrate containing equal amounts of both nitrogen forms may be found a suitable and convenient fertilizer to apply.

It is of great importance in the management of nursery soils to keep in mind the relationship that exists between the total soil fertility, as given in the proposed standards, the fraction of nutrients in the soil solution, and the content of nutrients actually required by seedlings during their 1- or 2-year period of growth.

The amount of a nutrient which is necessary for actual annual metabolism of forest seedlings constitutes, as a rule, but a small fraction of the total available supply of this nutrient present in a productive nursery soil. For example, the amount of calcium annually taken up by the growth of even calciphilous hardwood seedlings is less than 1 milliequivalent per 100 gm., or 400 pounds per acre. Nevertheless, a productive hardwood nursery soil must contain at least 5 milliequivalents per 100 mg. of replaceable calcium, or 2,000 pounds per acre. The presence of this high amount is vital because calcium fulfills numerous functions in soil besides that of a plant nutrient; it promotes aggregation, regulates reaction, counteracts the toxicity of other ions, and stimulates the activity of micro-organisms.

In nursery soils, exposed to rainfall and artificial irrigation, the fraction of nutrients in solution is subject to constant changes. During a period of abundant rainfall, the readily soluble salts are leached and the soil is saturated with nearly pure water. After the rains have stopped, additional nutrients are gradually released into the soil solution by hydrolysis and activity of micro-organisms from the more soluble minerals, exchange material, and organic compounds, i. e., from the storehouses of the plant nutrients (7).

The higher the reserve supply of nutrients, i. e., the level of total soil fertility, the higher, as a rule, is the level of the readily available fraction, the greater is the ability of the soil to resist depletion by leaching or plant feeding, and the greater is the assurance of an uninterrupted and balanced nutrition of seedlings.

Recent experience in several nurseries, located on sandy soils in the Lake States region, affords a striking illustration of the importance of total soil fertility upon the quality of nursery stock and the cost of its production. The summers of 1938 and 1939 were characterized by abundant and frequent rainfalls which caused severe leaching of nutrients, particularly soluble fertilizers applied prior to seeding. Early in July the depletion of plant food was manifested by the yellowing and general stagnation of seedlings as well as transplants. However, on soils of high total fertility the stock regained its color and vigor as soon as the precipitation decreased. On the contrary, on soils of low total fertility the signs of starvation became more and more apparent, and the quality of stock in some cases did not fully recover even at a high cost of liquid fertilizer treatments.

DISCUSSION

As early as the beginning of this century, Hilgard (*5*) repeatedly emphasized the far-reaching importance of analyses of soils supporting productive forest stands. In the preface of his classic text on soils he states:

> The natural floras and sylvas are thus the expression of secular, or rather, millenial experience, which if rightly interpreted must convey to the cultivator of the soil the same information that otherwise he must acquire by long and costly personal experience.

Hilgard (*5, p. 316*) particularly warned against—

> the futile attempts to deduce practically useful results from the chemical analysis of *soils long cultivated*, without first studying the less complex phenomena of *virgin* soils.

The ideas of Hilgard, expressed with reference to agronomical practice, are even more significant in relation to silviculture. The generally accepted concept of Mitscherlich's "optimum" growth arrived at on the basis of dry-matter production (*6*) is not applicable to the production of nursery stock. Stock having the maximum dry weight is too expensive to raise, and often difficult to plant. Such abnormally developed or unreasonably large "forced" seedlings are likely to show decreased vigor and poor survival on depleted and exposed cutover lands.

The fertility levels, derived from the analyses of natural seedbeds under productive forest stands, should give the closest approach to the physiological optimum of growth conditions; such fertility levels help to prevent not only the starvation of seedlings, but abnormal development and unreasonably high production of dry matter.

The analyses of virgin or nearly virgin soils give not only the amount of nutrients, which may be somewhat variable, but the normal ratio, or proportion of the various constituents, which is of great importance in a balanced nutrition of seedlings.

SUMMARY

The soils under productive stands of representative hardwood species (*Betula lutea, Acer saccharum, Tilia americana, Ulmus americana,* and *Fraxinus americana*) were analyzed for pH value, base-exchange capacity, total and available nitrogen, available phosphorus, available potassium, and replaceable bases. The average values obtained by means of statistical treatment of the results are suggested as standards for the maintenance of fertility in hardwood nursery soils. The analyses of soils showed that the nitrogen-phosphoric acid-potash ratio lies in the proximity of 1–2–5 for yellow birch and 1–3–5 for the rest of the hardwood species studied.

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EFFECT OF ROASTING AND SCALDING PIMIENTO FRUITS IN PREPARATION FOR CANNING ON THE SUBSEQUENT GERMINATION OF THE SEEDS[1]

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INTRODUCTION

Several thousand pounds of seed of the Perfection pimiento (*Capsicum frutescens* L.) are produced annually in Georgia as a byproduct of the canning industry. Some of the seed are sold to seed companies in the United States and some are shipped abroad, but the bulk of the stock is issued each spring by the canners to contract growers, who use the seed for the next year's crop. Since the fruits are either fire-roasted or scalded in oil to remove the skins for canning, the seeds are supposedly exposed to rather high internal temperatures. Most canners core their seed stock by hand before the skins are removed, but the question of the value of the seed from roasted and scalded fruits is being constantly agitated by growers since they can be obtained at little or no expense.

The investigations reported in this paper had as their object (1) to determine the influence of roasting and scalding Perfection pimiento fruits on the incidence and severity of the reduction in seed germination, and (2) to ascertain the types of seedling injury produced. Special attention was given to a study of the internal fruit temperatures to which the seeds are exposed.

Within recent years much has been added to the knowledge of the factors that affect the germination of seeds. So far as the writer has been able to find, however, the literature contains no work along this ling with peppers.

REMOVAL OF FRUIT SKINS

The two methods used in Georgia for removing the tough outer skins of pimientos prior to canning are not well known outside of the State. Since this investigation deals with the comparative effects of the two methods, a brief description of each is given.

THE ROASTING METHOD

Approximately 70 percent of the pimiento packing plants in Georgia use the roasting method for removing the skins. All the present-day roasters are of the rotary type, consisting of a 20-foot piece of 18-inch

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steel tubing with walls three-eighths of an inch thick and a cork-screw-fashioned baffle running lengthwise on the inside. Each unit is mounted between six rollers on a steel frame having approximately a 3-percent slope and is rotated by an electric motor, which makes it possible to adjust the speed of the roaster as desired. The roasters are fired with either crude oil or natural gas under pressure from a burner mounted at the lower end. This forces the hot flame practically the entire length of the roasters. The temperature of the roasters averages 900° C., and the fruits emerge charred black. After leaving the roasters the fruits are carried down a belt and through a rotary washer under pressure to remove the charred skins and finally into the hands of workmen who core, rewash, and pack them.

THE SCALDING METHOD

The scalding equipment consists of steel vats 2 feet wide and 20 feet long filled with a low-grade cylinder oil having a flash point of approximately 495° C. and mounted over a large furance. After the oil has attained a temperature of 425° the fruits are elevated into the vat and moved along through the oil by means of several large steel perforated paddles pulled by an endless chain. When the scalded fruits reach the far end of the vat, which takes on an average 42 seconds, they are dumped into a rotary washer where hot water and live steam under pressure remove many of the loosened skins and most of the oil. From the washer the fruits are taken to the packing plant on an endless belt, where they are washed by hand, cored, and packed.

EXPERIMENTAL PROCEDURE

During the 1938 pimiento canning season seed samples from roasted and scalded fruits were collected from 10 packing plants in Georgia for germination tests, and in 1939 similar samples were secured from the same canneries. The check treatment consisted of seeds from freshly picked ripe fruits that had not been heated.

By the use of a Hoskins type PA pyrometer, a minimum of 100 internal temperature readings were made of fruits by quickly inserting the thermocouple wire through the fruit wall into the locules surrounding the seeds at intervals after they had dropped from the roasters and scalding vats.

After the seeds had been removed from the fruits, 10 rows of 100 seeds each of all lots were sown one-half inch deep in flats 3 by 15 by 22 inches filled with a well-composted soil such as is ordinarily used by the growers as a planting medium in the hotbed. The flats were kept reasonably moist, and since the speed of germination of pepper seeds is known to be governed largely by the temperature to which they are subjected (*7*, *2*),[3] that of the greenhouse was maintained as nearly as possible between 70° and 85° F. After the seeds began to germinate, the flats were examined daily to make notes and seedling counts.

EXPERIMENTAL RESULTS

CONDITIONS SURROUNDING SEEDS DURING ROASTING AND SCALDING PROCESSES

Although internal temperature readings of fruits could not be made while the fruits were actually on their way through the roasters and

[3] Italic numbers in parentheses refer to Literature Cited, p. 228.

scalding vats, a knowledge of the temperatures to which they were subjected, the length of time they were exposed, and the subsequent fruit temperature readings (table 1), afforded a good indication of the conditions that surrounded the seeds.

TABLE 1.—*Comparison of average temperatures to which fruits were subjected for removing skins, and their effect upon the average internal temperatures surrounding the seeds*

Method used for removing skins of fruits	Average temperature to which fruits were subjected	Average length of time fruits were exposed	Average internal temperature of fruits—	
			At time of emergence from heating units	60 feet down belt where cores were removed
	° C.	*Seconds*	° C.	° C.
Fire roasting	900	30	71	45
Oil scalding	425	42	60	47

Table 1 shows that fruits that underwent the roasting process were exposed to an average temperature of 900° C. for 30 seconds. It is not surprising, therefore, that the internal temperature, to which the seeds were exposed, attained a height of 71° C. during the roasting process. Even after the fruits had traveled 60 feet on the belt and had gone through a washer of cold water under pressure, the temperature had dropped only to 45°. While the oil bath of the scalding method was held at approximately 425°, the fruits were 12 seconds longer in going through this medium than through the roasters. When the fruits emerged from the oil they had an average internal temperature reading of 60°, and by the time they reached the coring table the temperature had dropped only to 47°, which was 2° higher than that of the roasted fruits after they had traveled the same distance. This small difference was due largely to the fact that the cooked skins of roasted fruits were removed by running the fruits through a rotating washer of cold water under pressure, thus cooling them suddenly, while those of scalded fruits were removed by the same method but with live steam and boiling water.

SEED GERMINATION

The data in table 2 show that the percentage gernination of seeds from both fire-roasted and oil-scalded fruits was relatively low each year as compared with that of seeds from the untreated or check fruits.

TABLE 2.—*Average percentage germination of pimiento seeds from 10 canneries as affected by method of removing skins from the fruits for canning, 1938–39*

Cannery	Seed from fire-roasted fruits			Cannery	Seed from oil-scalded fruits		
	1938	1939	Average		1938	1939	Average
A	38.1	1.7	19.9	F	30.5	6.6	18.6
B	13.0	24.9	19.0	G	19.5	33.5	26.5
C	4.6	0	2.3	H	16.5	9.6	13.1
D	31.8	7.9	19.9	I	7.3	6.8	7.1
E	2.6	15.7	9.2	J	13.5	.5	7.0
Average [1]	18.0	10.0	14.0		17.5	11.4	14.5
Check	91.3	90.2	90.7				

[1] A difference of 33 percent is required for significance.

As a whole the average values for both methods were somewhat lower in 1939 than in 1938. However, upon comparing the 2-year averages it is of special interest to note that they closely agree, that for the roasting method being 14.0 percent and for the scalding method 14.5 percent. The remainder of the seeds were apparently rendered inactive by the heat treatments and failed to emerge. This, as well as figure 1, indicates that one method used for removing the skins of Perfection pimientos for canning was about as harmful to the subsequent germination of the seeds as the other.

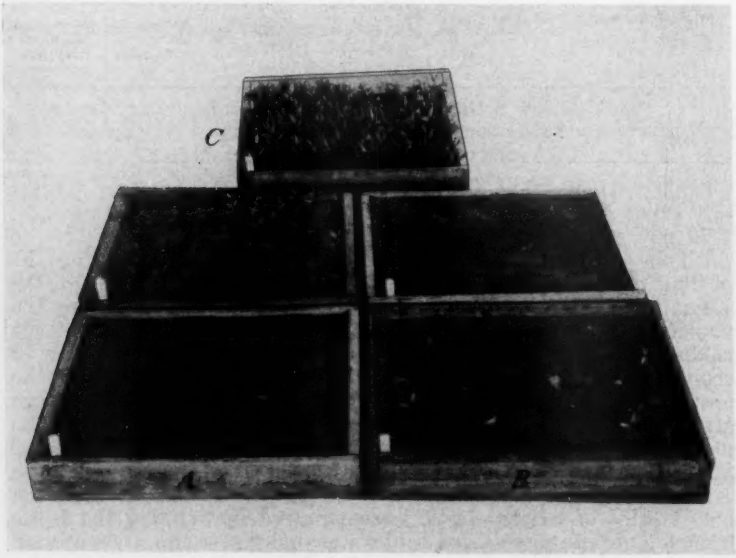

FIGURE 1.—Germination of pimiento seeds from fruits the skins of which were removed by (*A*) fire roasting and (*B*) oil scalding, as compared with checks (*C*).

In studying the data in table 2 in connection with those in table 1, it might seem that pimiento seed should be able to withstand higher temperatures without suffering such drastic reductions in germination. Dry seeds having hard seed coats (the morphology of which has been described by Cochran (*3*)), would, no doubt, react in this manner. In the case of wet seeds, however, attached to the placenta on the inside of the fruits, and consequently in an almost saturated atmosphere, the permeability of the seed coat is thought to be increased by the increase in the surrounding temperature, thus allowing the heat to penetrate and readily reach the embryo. This contention is substantiated by the findings of Denny (*5*) who, in using seeds from six species of plants, found that with some the permeability of the seed coat to water was increased tremendously by heating them.

SEEDLING INJURY

The normal germination process of the Perfection pimiento seed has been described in detail by Cochran and Cowart (*4*). The seed

consists of a small dormant plant surrounded by a thin seed coat. Upon the absorption of water this dormant plant resumes growth and within a relatively short time, under favorable conditions, it develops into a seedling consisting of the primary root, the hypocotyl, two cotyledons, the first pair of true leaves, and the plumule.

From the numerous germination tests that have been conducted on pimiento seeds by the Departments of Botany and Horticulture at the Georgia Agricultural Experiment Station, it has been known for some

FIGURE 2.—Abnormal seedlings that emerged from pimiento seeds from fruits the skins of which were removed by fire roasting or oil scalding: *A*, Adhering seed coat; *B*, baldhead; *C*, single cotyledon.

time that the heat treatments used for removing the fruit skins result in failure of many of the seeds to germinate. As a whole, however, the growers who have asked about the quality of the seeds from such fruits have not understood that, in addition to low vitability, there may be other types of damage that are not apparent until after germination. This damage usually manifests itself in the form of abnormal seedlings caused by adhering seed coats, baldheads, and single cotyledons (fig. 2). These abnormalities were not classified separately in this study, but collectively 4.7 percent of the seedlings which emerged from the treated seed were so affected. None, however, were noted in the check lots.

The failure of the seed coat to be released from the cotyledons is thought to be due in some measure, at least, to the heat which causes the embryo to stick to the seed coat; nevertheless, the fact is not overlooked that some of the damage was probably the result of certain defects in the seed coats themselves.

Baldhead is the result of abscission of the cotyledons and plumule, due for the most part to injury caused by the high temperature. Wester and Magruder (*8*) found that disease organisms caused the same condition in seedlings of the Baby Fordnook bush lima bean, while Bainer and Borthwick (*1*) and Harter (*6*) found that in several other types of beans it was due to internal injuries caused by the machinery used for threshing the seeds. On close examination the presence of baldhead in pimiento seedlings could be detected even before the seed coat was shed, as in most cases the severing took place at the base of the cotyledons, leaving only the bare hypocotyl. In beans the injury usually occurred above the cotyledons in the region of the plumule.

Single cotyledon was less prevalent than the two types of injury just described. It was found to be due to a failure of one of the cotyledons to develop further after being heated and not to pathogenic infection.

SUMMARY AND CONCLUSIONS

Fire roasting and oil scalding are the two methods used in Georgia for removing the outer skins of pimiento fruits preparatory to canning. Fruits having passed through the roasters emerged with their seeds exposed to an average internal temperature of 71° C. Fruits just out of the scalding vats had an average internal temperature of 60°, but were 12 seconds longer in passing through the oil medium than were those passing through the roasters.

The average germination of seeds over a 2-year period from roasted fruits was 14.0 percent and from scalded fruits 14.5 percent, indicating that one treatment was about as harmful to germination as the other.

Of the seedlings that emerged from the treated seeds, 4.7 percent showed such abnormalities as adhering seed coats, baldheads, and single cotyledons.

It is concluded from this work that Perfection pimiento seeds taken from either fire-roasted or oil-scalded fruits should neither be offered for sale nor used for planting.

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TWO ADDITIONAL FACTORS FOR RESISTANCE TO MILDEW IN BARLEY[1]

By ERNEST H. STANFORD, *graduate assistant in agronomy, University of California,* and FRED N. BRIGGS, *associate agronomist, California Agricultural Experiment Station*

INTRODUCTION

Since there are physiologic races of barley mildew (*Erysiphe graminis hordei*), the breeder of barley should have available a stock of varieties carrying different genes for resistance to this disease. Then if the distribution of races should shift or if new races of the pathogen should develop, he will have material and information which will enable him to meet the changed requirements for resistance.

In connection with a breeding program to develop mildew-resistant barley (*Hordeum vulgare*) suitable for California, Briggs, in 1932, began a study of the genetics of resistance to this disease. Thus far the genetics of resistance to race 3 of *Erysiphe graminis hordei* in eight resistant barley varieties has been established by Briggs (*1*, *2*),[2] Briggs and Barry (*3*), and Briggs and Stanford (*4*). Hanna, Goldfoil, Algerian, Kwan, and an unnamed variety S. P. I. 45492 were shown to differ from susceptible Atlas in one dominant factor for resistance. Crosses between these five resistant varieties showed that the factors in Hanna, Goldfoil, Algerian, and Kwan were different. S. P. I. 45492, however, had the same factor as Algerian, and the factors in Algerian and Kwan were shown to be linked. These factors have been designated as Ml_h, Ml_g, Ml_a, and Ml_k, respectively. The *Ml* indicates that the factor is for mildew resistance, and the subscript indicates the variety in which the particular factor was first found.

The three varieties Arlington Awnless, Chinerme, and Nigrate were found to have two dominant factors, each differing from the factors mentioned above, and each inherited independently of them. Furthermore, these varieties were found to have at least one factor in common. They were tentatively designated as Ml_x and Ml_y pending further investigation of their identity.

The present investigations deal with the inheritance of resistance to mildew in two additional varieties, Psaknon C. I. 6305 and Duplex C. I. 2433.

MATERIALS AND METHODS

The crosses studied were grown in greenhouse benches at Davis and Berkeley during the winters of 1938–39 and 1939–40. Thirty seeds were planted in rows 30 inches long and 5 inches apart, which usually gave 26 to 30 seedlings. They were inoculated in the three-leaf stage with race 3 of mildew, and classified as to degree of infection according to the system suggested by Mains and Dietz (*6*) and used previously (*1*, *2*, *3*, *4*). No attempt was made to distinguish between types 3 and 4. Plants showing type 4 infection were considered susceptible; those showing types 0, 1, or 2, resistant.

[1] Received for publication May 28, 1940.

[2] Italic numbers in parentheses refer to Literature Cited, p. 236.

Psaknon has given a mildew reading of 1 to 2 in greenhouse trials. It gave a reading of 0–1 to Tidd's (*8*) race 6 and a 0 reading to his race 7. Duplex has given a type 0–1 reaction to race 3 here. It has given a reading of 1 or less to all the races of Mains and Dietz (*6*), Mains and Martini (*7*), Tidd (*8*), and race A of Honecker (*5*), but a 2–3 reaction to Honecker's race B. Atlas has uniformly given a type 4 reaction to race 3.

Crosses between resistant Psaknon and Duplex and susceptible Atlas were grown to ascertain the number of resistant factors present. Crosses with other resistant varieties were grown to determine the identity of such resistant factors. Besides the F_2, the F_3 was grown when necessary. Every tenth row was seeded to Atlas, which always gave a type 4 reaction.

EXPERIMENTAL RESULTS

INHERITANCE OF RESISTANCE TO MILDEW IN HYBRIDS WITH PSAKNON

The F_2 and F_3 generations of the several crosses were grown concurrently. Table 1 shows crosses studied and results obtained.

TABLE 1.—*The classification of parents of F_2 plants and F_3 rows, as indicated, of the crosses named, grown in the greenhouse at Davis, Calif., 1938–39*

Parent or hybrid	Individual plants or rows	Generation	Observed			Expected			Ratio	Value of *P* for ratios indicated
			Resistant	Heterozygous	Susceptible	Resistant	Heterozygous	Susceptible		
			Number	*Number*	*Number*	*Number*	*Number*	*Number*		
Atlas	Plants				59					
Psaknon	do		27							
Psaknon × Atlas	do	F_2	349		100	337		112	3:1	>0.1
Atlas	Rows				14					
Psaknon	do		2							
Psaknon × Atlas	do	F_3	31	61	28	30	60	30	1:2:1	>.5
Psaknon	Plants		27							
Hanna	do		27							
Psaknon × Hanna	do	F_2	400		18	391.9		26.1	15:1	>.1
Psaknon	do		29							
Goldfoil	do		28							
Goldfoil × Psaknon	do	F_2	390		25	389.1		25.9	15:1	>.9
Psaknon	do		29							
Arlington	do		28							
Arlington × Psaknon	do	F_2	418		0					
Psaknon	Rows		2							
Arlington	do		2							
Arlington × Psaknon	do	F_3	110		0					
Psaknon	Plants		29							
Nigrate	do		26							
Psaknon × Nigrate	do	F_2	458		0					
Psaknon	Rows		2							
Nigrate	do		2							
Nigrate × Psaknon	do	F_3	83		0					
Psaknon	Plants		29							
Algerian	do		30							
Psaknon × Algerian	do	F_2	398		29	400.3		26.7	15:1	>.5
Psaknon	do		58							
Kwan	do		29							
Kwan × Psaknon	do	F_2	743		59	751.9		50.1	15:1	>.1

In the F_2 of Psaknon × Atlas there were 349 resistant and 100 susceptible plants. This result gives a probability greater than 0.1 on the basis of a 3:1 ratio, thus indicating the presence of a single dominant factor for resistance to race 3 of mildew. In F_3 there were 31 resistant, 61 segregating, 28 susceptible rows, all in conformity with expectations.

In the crosses between Psaknon and the four varieties Hanna, Goldfoil, Algerian, and Kwan, each of which is known to have a different factor for resistance, bifactorial ratios were obtained, indicating that the factor found in Psaknon differs from the four factors present in the varieties named above.

No susceptible plants appeared in F_2 or F_3 of Arlington × Psaknon and Nigrate × Psaknon, although Atlas checks invariably gave a type 4 reaction. The factor found in Psaknon must therefore be identical with one of the two factors previously reported in Arlington and Nigrate and temporarily designated as Ml_x Ml_y (*2*). Since the identity of one of these factors has now been established by its presence alone in the variety Psaknon, it will be designated as the Psaknon (Ml_p) factor and hereafter will replace the Ml_x factor designation in Arlington and Nigrate. The Ml_y factors in Nigrate and Arlington may or may not be identical. Until this point is definitely established, the factor will remain under its present designation. Although Chinerme was not crossed with Psaknon, results that will later appear indicate that one of the two factors is the Psaknon factor.

INHERITANCE OF RESISTANCE TO MILDEW IN HYBRIDS WITH DUPLEX

The crosses with Duplex are similar to those described with Psaknon, except that Psaknon was available as a tester for the Ml_p factor. Data from these crosses are recorded in table 2.

TABLE 2.—*The classification of parents or F_2 plants and F_3 rows, as indicated, of the crosses named, grown in the greenhouse at Berkeley, Calif., 1938–39, and Davis, Calif., 1939–40*

Parent or hybrid	Individual plants or rows	Generation	Observed			Expected			Ratio	Value of P for ratio indicated
			Resistant	Heterozygous	Susceptible	Resistant	Heterozygous	Susceptible		
			Number	*Number*	*Number*	*Number*	*Number*	*Number*		
Atlas	Rows				107					
Duplex	do		18							
Duplex × Atlas	do	F_3	154	127	8	167.1	117.4	4.5	37:26:1	>0.05
Duplex	Plants		26							
Hanna	do		29							
Duplex × Hanna	do	F_2	360		0					
Duplex	Rows		2							
Hanna	do		2							
Duplex × Hanna	do	F_3	103		0					
Duplex	Plants		29							
Goldfoil	do		55							
Duplex × Goldfoil	do	F_2	1,281		9	1,274.9		15.1	253:3	>.1
Duplex	do		26							
Kwan	do		58							
Duplex × Kwan	do	F_2	1,004		10	1,002.1		11.9	253:3	>.5
Duplex	do		26							
Algerian	do		57							
Duplex × Algerian	do	F_2	960		11	959.6		11.4	253:3	>.9
Duplex	do		58							
Psaknon	do		59							
Duplex × Psaknon	do	F_2	1,208		0					
Duplex	Rows		4							
Psaknon	do		4							
Duplex × Psaknon	do	F_3	105		0					
Duplex	Plants		27							
Chinerme	do		26							
Duplex × Chinerme	do	F_2	683		0					
Duplex	do		27							
Nigrate	do		26							
Duplex × Nigrate	do	F_2	413		0					
Duplex	Rows		2							
Nigrate	do		2							
Duplex × Nigrate	do	F_3	100		0					

Because of lack of seed, the F_2 of Duplex × Atlas was not grown. In F_3, 3 rows of 30 seeds each were planted from each F_2 plant after it had become apparent that comparatively few susceptible progenies existed in this population. It was possible, therefore, to identify more completely progenies segregating for the higher ratios of resistant to susceptible plants. In F_3 there were 154 resistant, 127 segregating, and 8 susceptible progenies, a result that suggests 3 independent factors for resistance, giving a probability of greater than 0.05 on this basis. Because the crosses between Duplex and the other resistant varieties indicate the partial constitution of Duplex, they will be considered next and the Atlas cross later.

In the F_2 and F_3 of Duplex × Hanna and Duplex × Psaknon no susceptible plants occurred, showing that Duplex contains the Hanna and the Psaknon factors. Susceptible plants were found in the F_2 of Duplex × Goldfoil, Duplex × Kwan, and Duplex ×. Algerian, indicating that the Goldfoil, Kwan, and Algerian factors were not present.

No susceptible plants were found in Duplex × Chinerme and Duplex × Nigrate as was expected, since Duplex and Nigrate contain the Psaknon factor and since, as pointed out, Chinerme probably contains the Psaknon factor.

Returning to the F_3 of Duplex × Atlas: The distribution of these progenies by percentage classes is shown in table 3.

TABLE 3.—*Distribution of parents and F_3 progenies of Duplex × Atlas into 5-percent classes for mildew susceptibility; grown at Berkeley, Calif., 1938–39*

Parent or hybrid	Progenies, with the percentage of susceptible plants indicated											
	0	1–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Duplex	18											
Atlas												
Duplex × Atlas	154	33	21	22	13	15	6	8	3	2		

Parent or hybrid	Progenies, with the percentage of susceptible plants indicated—Continued										Total
	55–60	60–65	65–70	70–75	75–80	80–85	85–90	90–95	95–100	100	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Duplex											18
Atlas										107	107
Duplex × Atlas			1	2	1					8	289

As pointed out earlier, there are 154 resistant, 127 segregating, and 8 susceptible progenies, a result which agrees satisfactorily with the numbers expected on the basis of 3 independent factors. Two of these have been identified as the Hanna and Psaknon factors. As shown by the occurrence of 4 segregating progenies falling between 65–80 percent of susceptible plants, the third factor is recessive and therefore different from any of those previously discovered. It will be designated hereafter as the Duplex (ml_d) factor for mildew resistance.

Except the 4 progenies which segregate 1:3, the segregating progenies overlap so that rows resulting from other genotypes cannot be identified. This gives 154 resistant, 123 segregating (61:3, 15:1, 13:3, 3:1), 4 segregating (1:3), and 8 susceptible progenies where 167.9, 107.6, 9.0, and 4.5 are the numbers expected on the basis of three independent factors. The fit between observed and expected would be improved considerably by assuming that the Duplex factor was rather loosely linked with either the Hanna or the Psaknon factor. As will be recalled, however (table 2), the number of susceptible plants obtained in the F_2 of Duplex×Goldfoil, Duplex×Kwan, and Duplex×Algerian all agreed with the numbers expected on the basis of independent factors. A strain of barley is being isolated which will carry the Duplex factor alone and which will be available not only as a tester for the factor but also for establishing its linkage relationship.

SUMMARY AND CONCLUSIONS

The occurrence of the two new genetic factors for resistance to race 3 of barley mildew is reported. The Psaknon (Ml_p) factor found in the Psaknon variety is dominant in effect and is identical with one of the two factors previously reported in Arlington Awnless, Nigrate, and Chinerme. Hereafter Ml_p will replace the Ml_x factor designation tentatively assigned to these three varieties.

A new factor found in Duplex combined with two previously identified factors, Ml_h and Ml_p, is recessive in effect and is designated as the Duplex (ml_d) factor.

The genetics of resistance to race 3 of barley mildew has now been studied at this station in 10 resistant varieties. The factorial composition follows:

Variety	*Factors for resistance to mildew*
Hanna	Ml_h Ml_h.
Goldfoil	Ml_g Ml_g.
Arlington Awnless	Ml_p Ml_p, Ml_y Ml_y.
Chinerme	Do.
Nigrate	Do.
Algerian	Ml_a Ml_a.
S. P. I. 45492	Do.
Kwan	Ml_k Ml_k.
Psaknon	Ml_p Ml_p.
Duplex	Ml_h Ml_h, Ml_p, Ml_p, ml_d, ml_d.

In all, there are seven different factors for mildew resistance—six dominant and one recessive. The number of factors in a single variety varies from one to three. Of the seven identified, two are definitely linked. The other five appear independent, although the Duplex factor may possibly be linked with either the Hanna or the Psaknon.

Additional factors for resistance to mildew may be found as other resistant varieties are investigated or as other races of mildew are used. Tidd (*9*), using race 6, found a single factor for resistance to mildew in a cross between resistant Nepal 595 and susceptible Featherstone. This factor must differ from any of the seven reported above because Nepal is completely susceptible to race 3.

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A SOLUTION OF NORMAL EQUATIONS GIVING THE STANDARD ERRORS OF THE CONSTANTS[1]

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Several statisticians (*1, 2, 3, 4, 5, 6, 7, 8, 9*) [2] have devised methods for solving normal equations which arise when fitting linear equations to observed data. Fisher (*3, pp. 142–150*) obtained a solution which enables one to find the standard errors of the constants by using his c values. The object of the present paper is to show how to solve for the constants by the use of calculating machines and how to find the c values, used in determining the standard errors of these constants. The material employed for illustrating the method is that used by Fisher to show the dependence of rainfall on longitude, latitude, and altitude.

Assume that the predicting equation for predicting values of y from given values of x_1, x_2, and x_3 is

$$y=b_1x_1+b_2x_2+b_3x_3.^3 \tag{1}$$

The normal equations arising from the least squares method are:

$$\begin{aligned}
\Sigma x_1^2 \cdot b_1+\Sigma x_1x_2 \cdot b_2+\Sigma x_1x_3 \cdot b_3&=\Sigma x_1y,\\
\Sigma x_1x_2 \cdot b_1+\Sigma x_2^2 \cdot b_2+\Sigma x_2x_3 \cdot b_3&=\Sigma x_2y,\\
\Sigma x_1x_3 \cdot b_1+\Sigma x_2x_3 \cdot b_2+\Sigma x_3^2 \cdot b_3&=\Sigma x_3y.
\end{aligned}$$

By using the values of the summations given by Fisher the above equations become

$$1{,}934.1b_1-\ 772.2b_2+\ 924.1b_3=1{,}137.4=\Sigma x_1y, \tag{2}$$
$$-772.2b_1+2{,}889.5b_2+\ 119.6b_3=-592.9=\Sigma x_2y, \tag{3}$$
$$924.1b_1+119.6b_2\ +1{,}750.8b_3=\ 891.8=\Sigma x_3y. \tag{4}$$

Divide each equation by the absolute value of the coefficient of b_1 in it, and we get

$$b_1-0.399255b_2+0.477793b_3=0.588077=0.000517036\Sigma x_1y \tag{5}$$
$$-b_1+3.741906b_2+0.154882b_3=-0.767806=0.00129500\Sigma x_2y \tag{6}$$
$$b_1+0.129423b_2+1.894600b_3=0.965047=0.00108213\Sigma x_3y \tag{7}$$

Eliminate b_1 as follows

$$\begin{aligned}
(8)=(5)+(6):\quad & 3.342651b_2+0.632675b_3=-0.179729\\
&=0.000517036\Sigma x_1y+0.00129500\Sigma x_2y,\\
(9)=(6)+(7):\quad & 3.871329b_2+2.049482b_3=0.197241=0.00129500\Sigma x_2y\\
&\qquad +0.00108213\Sigma x_3y,
\end{aligned}$$

or

$$b_2+0.189273b_3=-0.0537684=0.000154678\Sigma x_1y \tag{10}$$
$$+0.000387417\Sigma x_2y,$$
$$b_2+0.529400b_3=0.0509492=0.000334510\Sigma x_2y \tag{11}$$
$$+0.000279524\Sigma x_3y.$$

Eliminating b_2 gives

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[2] Italic numbers in parentheses refer to Literature Cited, p. 239.

[3] Where the variables are measured from the mean.

$$0.340127b_3=0.104718$$
$$=-0.000154678\Sigma x_1y-0.000052907\Sigma x_2y+0.000279524\Sigma x_3y,$$

or

(12) $$b_3=0.307879 \quad +$$
$$=-0.000454765\Sigma x_1y-0.000155551\Sigma x_2y+0.000821822\Sigma x_3y,$$

or

(13) $$b_3=c_{13}\Sigma x_1y+c_{23}\Sigma x_2y+c_{33}\Sigma x_3y,$$

where
$$c_{13}=-0.00045477,$$
$$c_{23}=-0.00015555,$$
$$c_{33}=0.00082182,$$

which are essentially the same as Fisher obtained.

As a check upon the computations, b_3 can be found from (13) by using the values of c_{13}, c_{23}, c_{33} and the values of Σx_1y, Σx_2y, and Σx_3y; this is

$$b_3=-0.00045477(1,137.4)-0.00015555(-592.9)+0.00082182(891.8),$$

or

$$b_3=0.307876=0.30788.$$

Solve for b_2 by substituting the value of b_3 in (11),

$$b_2=-0.529400(0.30788)+.0509492=-0.11204$$

$$=0.529400[-0.000454765\Sigma x_1y-0.000155551\Sigma x_2y+0.00821822\Sigma x_3y]$$
$$+0.000334510\Sigma x_2y+0.000279524\Sigma x_3y$$

or

$$b_3=+0.000240753\Sigma x_1y+0.000416859\Sigma x_2y-0.000155550\Sigma x_3y,$$

or

(14) $$b_2=c_{12}\Sigma x_1y+c_{22}\Sigma x_2y+c_{23}\Sigma x_3y,$$

where
$$c_{12}=0.00024075,$$
$$c_{22}=0.00041686,$$
$$c_{23}=-0.00015555.$$

The value of b_2 can be checked by the use of (14); this gives

$$b_2=-0.11204.$$

Equation (7) may be used to find b_1 by substituting the values of b_2 and b_3; this gives

$$b_1=-0.129423(-0.11204)-1.894600(0.30788)+0.96047=0.39624$$
$$=-0.129423[0.000240753\Sigma x_1y+0.000416859\Sigma x_2y-0.000155550\Sigma x_3y_i]$$
$$-1.894600[-0.000454765\Sigma x_1y-0.000155551\Sigma x_2y+0.000821822\Sigma x_3y_i]$$
$$+0.00108213\Sigma x_3y,$$

or

$$b_1=+0.000830439\Sigma x_1y+0.000240756\Sigma x_2y-0.000454766\Sigma x_3y,$$

or

(15) $$b_1=c_{11}\Sigma x_1y+c_{12}\Sigma x_2y+c_{13}\Sigma x_3y,$$

where
$$c_{11}=0.00083044,$$
$$c_{12}=0.00024076,$$
$$c_{13}=-0.00045477.$$

By the use of (15), $b_1=0.39624$.

The standard errors of the b's can now be obtained from (13), (14), and (15) by rewriting these equations. For example (13) may be written as follows:

$$\begin{aligned} b_3 &= c_{13}[x_{11}y_1 + x_{12}y_2 + \ \ldots \ + x_{1n}y_n] \\ &\quad + c_{23}[x_{21}y_1 + x_{22}y_2 + \ \ldots \ + x_{2n}y_n] \\ &\quad + c_{33}[x_{31}y_1 + x_{32}y_2 + \ \ldots \ + x_{3n}y_n], \end{aligned}$$

or

$$\begin{aligned} &= (c_{13}x_{11} + c_{23}x_{21} + c_{33}x_{31})y_1 + (c_{13}x_{12} + c_{23}x_{22} + c_{33}x_{32})y_2 \\ &+ \ \ldots \ + (c_{13}x_{1n} + c_{23}x_{2n} + c_{33}x_{3n})y_n \\ &= \Sigma(c_{13}x_{1i} + c_{23}x_{2i} + c_{33}x_{3i})y_i. \end{aligned}$$

The quantity b_3 is linearly related to the y values, for the x values are fixed. The standard deviation of the values of the y's for any value of x is assumed to be the same for each value of x; that is, the standard deviation of each y array on x is the same. The standard error of b_3 is therefore

$$\sigma b_3 = S_y\sqrt{c_{13}^2\Sigma x_1^2 + c_{33}^2\Sigma x_2^2 + c_{33}^2\Sigma x_3^2 + 2c_{13}c_{23}\Sigma x_1x_2 + 2c_{13}c_{33}\Sigma x_1x_3 + 2c_{23}c_{33}\Sigma x_2x_3}$$

where S_y is the standard error of estimate.

By the use of determinants the last expression can be reduced to

$$\sigma b_3 = S_y\sqrt{c_{33}}.$$

The standard deviation of b_3 is hence

$$\sigma b_3 = 4.3327^4\sqrt{0.00082182} = 0.12421.$$

In a similar way the standard deviations of b_1 and b_2 can be shown to equal respectively

$$\sigma b_1 = S_y\sqrt{c_{11}} = 4.3327\sqrt{0.00083044} = 0.12486,$$

and

$$\sigma b_1 = S_y\sqrt{c_{22}} = 4.3327\sqrt{0.00041686} = 0.08846.$$

The values of the constants with their standard errors are

$$\begin{aligned} b_1 &= 0.39624 \pm 0.12486, \\ b_2 &= -0.11204 \pm 0.08846, \\ b_3 &= 0.30788 \pm 0.12421. \end{aligned}$$

The above method shows how to find the c values and also the regression constants and can be used with modern calculating machines. This method is not only easy to follow, but is also easy to teach to computers.

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